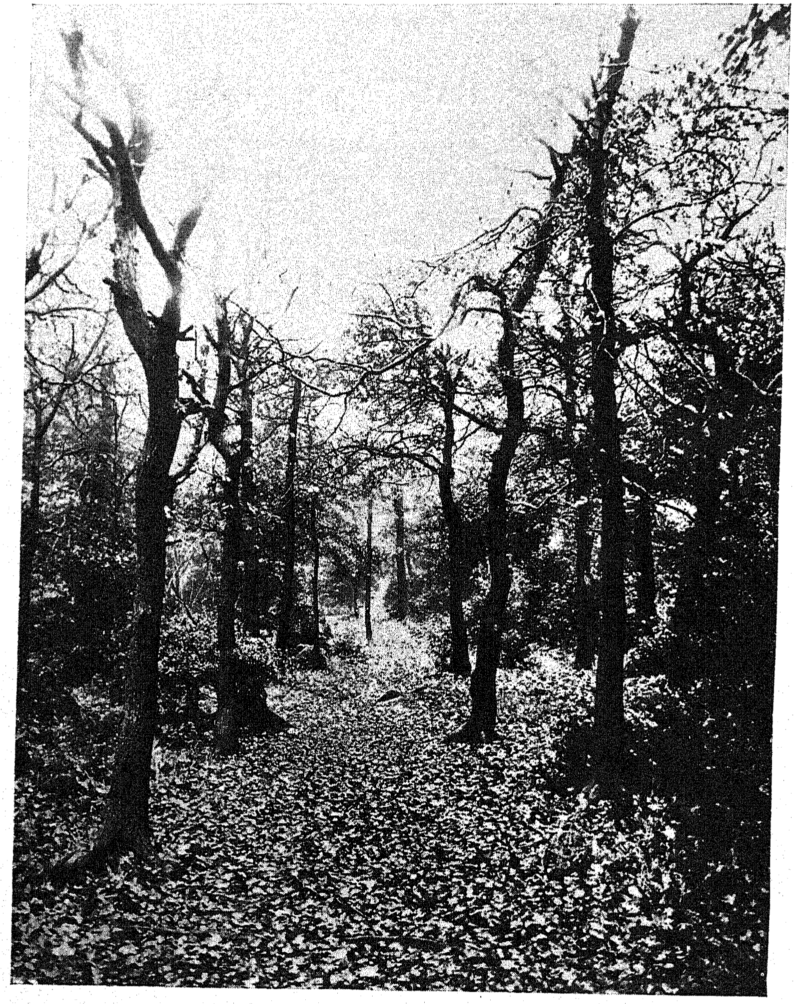

FOREST LITTER.

(From the Dencer Whittles' collection of photographs, by kind permission of Prof. Seward, Botany School, Cambridge.)

THE EVOLUTION AND CLASSIFICATION OF SOILS

BY

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Author's Preface to the German Edition

THE following is an attempt to summarise the fundamental facts of the formation of soils, to consider the close connection between climate and soil in greater detail, to indicate how soils are related to one another and so lead up to a classification of soil types, a system of soils, which rests on a true scientific basis.

As to how far this has been achieved must be left for the future to decide. Numerous attempts have been made in the past to classify the bewildering variations of soils without soil investigators being agreed as to the general principles to be adopted.

Every classification of soils that has been in use up to the present has its advantages, each gives prominence to definite properties of the soil; each system distorts definite conceptions of a number of soil properties in the mind of an experienced worker. The object of a growing science cannot be to do away with valuable old data, but to arrange these on an extended basis and by this means make them really comprehensible for the first time. Hence, in the proposed classification, a place is found for each of the schemes so far put forward. An attempt is made to utilise them within the limits of their significance. We need only take as an example the old classification of soils according to their texture into sands, loams and clays. These expressions are at once associated with a picture of important soil properties—the conductivity for water, aeration, warmth, etc., of the soils are called to mind. On the other hand, other peculiarities are not expressed. It is, therefore, just as inadvisable to give up these expressions as it is to make them a basis for the classification of all soils.

The same holds good, for instance, in the case of the soil's conductivity for water. A sufficient water content is not only a necessary condition for the life of organisms, but the water itself exercises a far-reaching influence on the processes of soil formation and on the changes which take place in the

soil. There is no doubt that, if it is desired to regard all soils from ONE point of view alone, the action of water is the most suitable basis on which to build up a classification of soils. Soils, however, are the products of very different actions of which that of water is certainly the most important, but is only ONE. By considering this to the exclusion of all others, we arrive at a classification which can roughly be compared with that of Linnæus in the case of plants: built upon a uniform plan, it is well adapted to permit a rapid survey, and yet is not in a position to display the inner continuity of the whole.

The system for the classification of soils proposed by the author rests on a climatic basis. Soils are the result of weathering, which also includes the action of water and the decay of the dead parts of plants. Weathering depends on the climate, which impresses the products of weathering with varying properties, which, however, are similar in districts having the same climate. Further, the effects of plants and animals on soils depend, like all organic life, on the climate.

The rocks from which soils arise vary both in composition and in properties. The products of their weathering will differ more or less from one another. But the influence of the rock is naturally limited by its distribution.

A similar state of affairs is found in the case of the distribution of water in the soil. The total quantity of water present is determined by the climate, but locally may be greatly influenced by an inward flow of water as well as by a slower or more rapid removal of water. The nature of the rock as well as the conductivity of the soil for water are influences which affect the properties of the soil locally. They may be restricted to small areas or may embrace entire countries, though as compared with the effect of climate they can only be considered as local occurrences.

Plants and animals live on and in the soil. There is a very close relationship between the living and non-living portions of the soil, even if this has been but little investigated up to the present. One of the most attractive problems of Soil Science is the investigation of the intimate connection

between soils and organisms and the proof of their interdependence. It is slowly coming to light that this is a question, not of a chance occurrence, but of intimate reactions—metaphorically of symbioses—between the organic and inorganic kingdoms. The influence of organisms on the soil varies with the variation of the flora and fauna. These are actions which are limited by definite external conditions, which are of great importance as regards the practical utilisation of the soil, but can be applied only to a limited extent to the classification of soils.

If we take the effects of climate as a basis we naturally arrive at the following classification of soil types:—

1. *Climatic Soil Zones and Regions.* The soils have peculiarities in common which are produced by the climate.

2. *Local Soils.* Within the Climatic Soil Zones the Local Soils form sub-divisions which display varying properties determined by special influences (parent rock, water conductivity, texture, situation, etc.)

3. *Soils influenced by Organisms.*

All types of soil may be arranged in these three groups.

The first two groups are alone suitable for the preparation of soil maps, since these are lasting influences to which the soil is subjected.

Whereas other branches of scientific investigation have been independent for a long time, Soil Science has still to fight for recognition. Its heaviest burden is its present dependence on Agricultural Chemistry, which, primarily an Applied Science, has to subserve practical purposes. Soil Science has other ideals. It is to be dedicated to the unfettered examination of the soil as an independent branch of knowledge. The scientific investigation of the soil completes the circle of the Natural Sciences and will first make Man completely master of the earth.

Experience has shown that the results of unrestricted investigation indicate the way to attain objects of the greatest practical value. There is no reason for assuming that Soil

Science will not also lead to results of practical value. It alone is in the position to show the agriculturist how to utilise his most important means of production, the soil, with certainty. It is one of the worst mistakes, unfortunately still common everywhere, to question the practical value of the results of scientific work. Science, like all other branches of learning, is itself an ultimate objective. It has to advance human knowledge, without being encumbered by the question as to whether it is possible to make immediate practical application of the results.

During the course of the last twenty years the scientific investigation of soils has made great strides. The advances of Colloid Chemistry have opened up new views; the application of the methods of Physical Chemistry has enabled us to tackle problems which formerly seemed scarcely soluble. But not only Art, but Science as well, has unfortunately to seek a livelihood. Up to the present there are no Professorial Chairs for Soil Science. Only the Forestry Schools of Northern Germany and the University of Munich possess the equivalents of Professors of Soil Science. In this respect Germany is behind other countries; as she is unfortunately also, in the lack of possession of such a Research Institute as, for instance, the United States of America have in the Bureau of Soils, which is chiefly concerned in the scientific investigation of soils.

The author publishes this small work with the hope that it will win new friends for the fascinating and extraordinarily complicated Science of Soils, and that it may extend the scope of our knowledge of soils.

E. Ramann Univ.-Prof.

MÜNICH,
October, 1917.

Kgl. bayrische forstliche Versuchsanstalt.

Translator's Note

In the following translation an endeavour has been made to adhere as closely as possible to the German text; where it was thought that a slight divergence would result in a clearer rendering, the alteration has either been noted in a footnote or the German term has been given in brackets. Considerable trouble has been taken in trying to find suitable English equivalents for the names of the soil-types. Where the soil type has an obvious representative in this country, the name in general use was adopted, as for instance in the case of Meadow Soils, Fen, etc. On the other hand, "Reef Soils" and "Warp Soils" must be regarded as only tentative. Others, again, do not lend themselves to translation and have been retained in their original form, e.g. Knick, Glei, etc.

Advantage has been taken to include a few additional notes and references, mostly to English literature. Those, for which the translator is responsible, bear his initials.

The manuscript has been submitted to the author.

The translator desires to acknowledge his gratitude to Messrs. L. F. Newman, M.A., F.I.C. and Raymond Priestley, M.A., for their criticism and helpful suggestions.

C. L. Whittles.

Downing College, Cambridge,
February, 1928.

CONTENTS

PAGE

AUTHOR'S PREFACE TO THE GERMAN EDITION - v

TRANSLATOR'S NOTE - - - - - - - ix

INTRODUCTION - - - - - - - - I

Definition of Soil, 1. Climatic Factors, 2. Soil Climate, 3. Agencies of Soil Formation, 5.

I. WEATHERING - - - - - - - - 6

Disintegration of Rocks, 6. Decomposition of Rocks, 6. Hydrolysis, 9.

II. ACTION OF THE WATER CIRCULATING IN THE SOIL - 12

Classification of Soil Water, 12. Action of Water percolating downwards, 14. Colloids, 15. Action of ascending Currents of Water, 16. Crystallisation Concentration, 17. Decomposition of dissolved Substances, 18. Carbonates, 19. Iron, 20. Alumina, 21. Formation of Humus, 22. Forms of Humus, 22.

LOCAL SOILS - - - - - - - - - 24

Influence of Parent Rock, 25. Carbonates, 26. Loess, 27. Texture, 29. Situation, 30. Fixity of Soils, 32. Soils receiving continual Additions of Material, 34. Geological Age of Soils, 36. Change of Climate, 36.

III. THE ACTION OF ORGANISMS ON THE SOIL - - 38

Plants, 38. Fungi, 39. Higher Plants, 39. Influence on the Soil Climate, 40. Plant Communities, 40. Woodland, 40. Grassland, 42. Cultivated Soils, 44.

IV. THE CLASSIFICATION OF SOILS - - - - - 46

Bleached Earths, 47. Black Earths, 48. Brown Earths, 48. Red Earths, 48. Laterite, 49.

ARID AND HUMID ZONES - - - - - - 49

Arid Soils, 49. Humid Soils, 49. Soils in Districts having a periodic Climate, 50. Chemical Composition, 54.

CLASSIFICATION AND BOUNDARIES OF THE CLIMATIC SOIL ZONES - - - - - - - - 54

Succession of Strata in Humid and Arid Soils, 55. Soil Zones and Soil Regions, 59.

PAGE

V. THE CLIMATIC SOIL ZONES - - - - - - 62

THE SOILS OF COLD ZONES - - - - - 62

Tesselated Soils, 62. Hillock Tundra, 63. Peat Hillock Tundra, 63. Frost-shattered Soils, 64. Mountain Meadow Soils, 64. Mountain Peat Soils, 64. Ice Soils, 65.

THE SOILS OF THE COOL-TEMPERATE ZONES AND REGIONS - - - - - - - - - 65

Northern Grey Earths, 66. Podsol, 68. Pan, 69. Forest Bleached Earths (Grey Forest Soils), 70.

LOCAL SOILS OF THE NORTHERN BLEACHED EARTHS 72

(1) *Sub-aqueous Soils*, 73. Mud or Sapropel, 73. *Humus Soils*, 74. Fen, 75. Carr or Wood Peat, 76. "Mosses" (High Moor, Upland Peat), 77. Peat Destroyers, 78. Vegetable Mould, 78. Successions of Peats, 78. Weathering of Peat Soils, 79.

(2) *Soils under the Influence of the Ground Water*, 80. Glei Soils, 81. Meadow Soils, 81. Sandy Meadow Soils, 81. Meadow Soils on Clay, 82. Limonite Soils, 82. Warp Soils, 83. Marsh Soils, 84. Saline Soils, 85. Flowing Earths, 85.

THE BROWN EARTHS - - - - - - - 85

Calcareous Soils, 88. Karst Red Earths (Terra-rossa), 92. Reef Red Earths, 93.

THE SEMI-ARID SOILS OF THE TEMPERATE ZONES 93

Steppe Black Earths, 94. Chestnut-Brown Soils, 97. Steppe Bleached Earths, 99.

SALINE OR ALKALI SOILS - - - - - - 102

SUB-TROPICAL SOILS - - - - - - - 104

Sub-Tropical Red Earths, 105. Sub-Tropical Black Earths, 105. Regur, 105. Crusting Soils, 106. Desert Soils, 107.

THE SOILS OF THE TROPICS - - - - - 107

Laterite, 109. Savannah Soils, 110.

VI. SUMMARY OF THE CLASSIFICATION OF SOILS - - 114

Table (facing page 118).

NOTES AND REFERENCES - - - - - - 119

SUBJECT INDEX - - - - - - - - 123

AUTHOR INDEX - - - - - - - - 128

INTRODUCTION

It is only recently that a start has been made in the investigation of soils, and only during the last fifteen or twenty years that a large number of workers have devoted themselves to the task of examining soils in different ways; at present there is no doubt that a lively interest is displayed in the study of Soil Science. The period, during which the properties of soils were studied only with regard to their practical application to the growth of plants, is now drawing to a close, and the newer view is beginning to meet with general approval—the view that the soil should be considered as a subject for pure scientific research, in accordance with a principle that has been recognised for many years in all other branches of Natural Science.

The surprisingly backward state of the subject as compared with that of other branches of scientific investigation is probably due in no small degree to the soil's lack of individuality. The eye recognises the plant world in its various aspects as forest, field, steppe or savannah; the animal kingdom attracts attention by the power of movement displayed by many of its members, but the soil is usually hidden from observation under a covering of living or dead plants. Even if the structure of the soil is revealed, as in a cutting, the eye lights more readily on the projecting rock than on the inconspicuous layer in which the roots of plants are distributed.

The soil is the uppermost weathered layer of the solid crust of the earth; it consists of rocks that have been reduced to small fragments and have been more or less changed chemically, together with the remains of plants and animals that live on it and in it.[1]

Weathering depends on the climate; its progress and products vary according to the temperature and the rainfall.

Similarly we see that in the case of plants and animals, the possibility of their survival and increase is determined by the climate. The soil is the result of the weathering of rocks modified by the presence of organic life and of the remains of past organisms. Since both these cycles depend on climatic conditions, the soil itself must obviously depend on the climate too. We know from experience that the more extreme the climate the more uniform do the properties of soils become, until at last the parent rock and the configuration of the country cease to exert any influence, and a wide expanse of land of varied structure and topography is found covered with the same soil. The Steppes of Eastern Europe and the Prairies of North America have the same type of soil, Black Earth, well known on account of its fertility. This soil extends for thousands of square miles without any appreciable change in its properties.

Soils are much more varied in a temperate climate, especially if the seasonal changes are marked. The variations in the nature of the soil are shown in relation to both the parent rock and the situation. Frequently the soil is found to change greatly in character even within small areas. It is only by the comparison of a large number of soils that one is able to recognise the general type underlying the frequently bewildering variety.

We shall arrive at a clearer understanding of the processes of the formation of soils if we take *Climate* as our starting point.[2]

The *Climatic Factors* are:—

1. *Temperature*; its maximum, minimum and mean values. The frequency of temperature variations, and the periods during which the temperatures are above and below the freezing point of water are especially important as regards the formation of soils.

2. *Precipitation*. The amount of water supplied as rain and snow, its distribution during the course of the year, the amounts which fall in single storms are, all important.

3. *Evaporation*. The relation between the quantity and frequency of the precipitation and the amount of the evapora-

tion, and the variation of this ratio during the course of the year are of fundamental importance for soils as well as organisms, especially plants.

Meteorology for the most part considers the degree of moistness of the air. In this connection it cannot be pointed out too often or too emphatically that the humidity of the air has no direct significance either for the life of organisms or for weathering and soil-formation, but that it is the amount of evaporation and the evaporation alone that exerts the most important modifying influence on vegetation and soil formation. The air humidity data of meteorological observations are so far the only material available to give any idea of the amount of evaporation.[3]

Soil Climate. The climate of the soil differs greatly, in some ways vastly, from that of the air. The scope of the investigations which have been conducted up to the present on the climate of the soil is very limited, as they are mostly concerned with the effects of a covering of plants or snow, etc., on the temperature of the soil. Among soil workers, Wollny in particular has published numerous investigations on the influence of soil coverings, as well as of physical properties such as grain size and stratification.[4] The temperature of the soil diverges greatly from the prevailing temperature of the air, varying in greatest measure at the surface and in the uppermost layer during the course of a day and a year, while at a depth of 70 cm. the daily, and at 10 to 20 cm. the yearly variations cease to attain measurable values.[5] The temperature of the surface soil influences in a high degree the amount of evaporation, and consequently affects the movement of water in the soil.

In nature, the presence or absence of a plant covering produces very marked differences in the temperature of the soil. In general, the effect of a vegetative covering is to lower the average soil temperature, as compared with that of bare soils, during the time that the daily and annual temperatures are highest. Since evaporation is also reduced, the general effect is the same as would be produced if the soil were removed to a cooler and moister climate.

There is no doubt that the surface of a dry soil exposed to direct insolation attains a very high temperature. We do not yet know the actual maximum attained, but it is so high that plants exposed to it are injured, even in temperate regions.

The influence of insolation is especially felt on slopes, the sides of mountains and similarly exposed situations, with the result that on such places the formation of a distinct type of soil may be brought about, which differs from the soils of the surrounding district. Examples of soils of this type, known as "Reef Soils" (Randböden), are found on limestone in the Jura Mountains of Southern Germany; probably part of the Red Soils of the Mediterranean region should also be included in this type.

Differences in the amount of insolation to which a soil is exposed produce considerable effects on the climate of the soil, and this can frequently be observed even within comparatively small areas. The only investigations in this connection appear to be those of Krauss in an examination of the limestone soils in the neighbourhood of Wurzburg.[6]

The climate of the soil is a potent factor in the formation of soils, and is responsible for the fact that even within the same climatic boundaries different soils are formed under different vegetative coverings, e.g. forest and steppe. A type of soil originally present may be completely transformed by such a change in the flora of the country. This action must be most marked in tropical countries, although up to the present no observations have been made. It can be assumed that the higher the temperature and the greater the possible evaporation, the greater will be the effect produced on the soil by a vegetative covering.

An important peculiarity about the soil climate is that the soil atmosphere is almost certain to be saturated with moisture.[7] Plants and plant-organs which live more or less permanently in the soil, as well as soil animals, do not require any protection from evaporation, and so far as the structure of their skin is concerned, resemble aquatic organisms rather than those which live in the air. No observations are available as to the vapour pressure of the soil atmosphere in extremely

dry countries; from individual descriptions of the action of dry winds on vegetation it seems clear that the saturation deficit of the soil air can at times, at all events, attain a high value.[8]

In considering the action of climate on the formation of soils a careful distinction must be made between the climates of the atmosphere and of the soil. In many cases this is sufficient to explain soil variations.

The Agencies of Soil Formation are:—

I. *Weathering*, which may be divided into (1) Physical or Mechanical Weathering in which the rocks are disintegrated and pulverised, their chemical composition remaining unaltered, and (2) Chemical Weathering, which results in the decomposition of rocks.

II. The action of the water circulating in the soil.

III. The action of the remains of dead organisms, especially plants (humus).

We must now consider how these soil-forming agencies influence the type of soil produced.

Chapter I

WEATHERING

Physical Weathering or the disintegration of rocks is brought about:—

1. By changes in volume as a result of variations in temperature.

2. By the shattering action of freezing water, which increases in volume by one-eleventh on conversion into ice. Liquid water enters cracks and crevices in the rock and on freezing explosively disrupts the rock. With frequent changes in temperature above and below the freezing point large masses of rock may be shattered and converted into heaps of fragments of much smaller sizes. Though frost action attains its greatest effects in the frigid zones and on the tops of high mountains, it is also of great importance as an agency of soil formation in temperate regions.

3. By the pulverisation of rocks during transport by ice (glaciers) or flowing water. The fragments abrade each other as they are carried along and so are gradually reduced in size and, if the process is carried to its logical conclusion, are converted into fine "rock flour." If transport is effected under water, in addition to the mechanical reduction in size, extensive chemical decomposition takes place, a thing which does not take place during transport by glaciers.

4. By sand, which, when driven by the wind, polishes and grinds away exposed rocks.

Chemical Weathering, or the decomposition of rocks, includes all those actions which bring about a change in chemical composition and result in the formation of new substances. Whereas in physical weathering the rock is reduced to small fragments, the chemical composition being unchanged, chemical weathering attacks the substance itself and leads to the

formation of other chemical compounds that were not present in the original rock.

The *silicates* are the most important and commonest of the soil-forming minerals. Their weathering involves complicated reactions the details of which have not yet been fully explained, and whose progress not only depends on the climatic conditions, but is also influenced by the properties of the resulting compounds. Under different conditions the same parent rock may give rise to extremely different products as a result of weathering.

In chemical changes, as a rule, several different chemical reactions take place simultaneously. The majority of chemical reactions are influenced by the concentration of the reacting solutions. We may express these ideas somewhat as follows. In solutions, the molecules and their electrically charged dissociation products, the ions, are in continuous and unrestrained motion; if two or more of these unit bodies collide with one another, they react with one another according to their properties. The collision may lead to the decomposition of one compound, or to the formation of another. Consequently, in a solution, changes are continually taking place, the reacting bodies continually uniting and continually separating; this must lead to the actual formation of all those compounds which are capable of existence. The proportions in which they are found in the resultant complex depends on the relation between their rates of formation and their rates of decomposition. If union preponderates, a particular substance will be present in abundance in the solution; if decomposition is more rapid then it will only be present in mere traces. These changes are continually taking place in the solution, and so long as the external conditions are not altered, especially temperature and concentration (i.e. the quantities of the reacting bodies present per unit volume), a state of equilibrium is finally attained for each set of conditions.

If the external conditions are altered, for instance the temperature, the stability of the molecules and ions increases or decreases, the persistence of the compounds formed is increased or diminished; in short, new relationships come into

action which may be favourable or unfavourable to one or other of the compounds. The quantitative relationship between the resultant products has thus a fresh value, the course of the reaction is altered, and a new state of equilibrium is established. This may result, for instance, in a substance which is formed in traces only at low temperatures, being present in large amounts at higher temperatures. The chemical reactions are still the same, but their limitations have changed. From this it is clear that the same chemical reactions may result in the formation of very different products according to the conditions.[9] This important principle is of great and far-reaching application in the formation of soils.

The direction of chemical reactions however is affected not only by the external conditions but also by the presence of larger or smaller proportions of the individual substances. This is easily understood. Suppose we have a solution of two salts that act equally on one another. The number of molecular and ionic collisions must be the same. Now suppose we add as much of one of the salts as was present originally, that is we double the concentration of one of the salts. The result of this will be that the units of the salt present in smaller quantity will collide twice as often with the units of the salt present in larger quantity, than they did at first. The equilibrium is displaced in favour of the substance present in larger quantity, or, since we are dealing with solutions, in the direction of the substance present in higher concentration. The greater mass (concentration) produces the greater effect; this is the basis of the law of Mass Action. If we gradually increase the concentration of one of the salts to such an extent that the concentration of the other becomes very low in comparison, the reaction proceeds in favour of the salt present in excess, and since this holds good for either of the two salts, the result of the reaction depends on the reacting masses (concentrations).

Reactions which may lead at times to the formation of one substance, at other times to the formation of another, according to the given conditions, are termed "reversible."

These are of fundamental importance in the study of soils and of the changes taking place in them.

Applying these principles to the processes of weathering and soil formation, we arrive at the following conclusion:—

The chemical changes involved in the weathering of rocks and the formation of soil are really the same in different climates; the external conditions, especially the prevailing temperature, determine both the direction and the rate of the reactions.[10]

The weathering of the silicates is best considered by taking the action of water as our starting point. Water is only slightly "active" chemically; on the other hand, rain and snow continually furnish the soil with fresh supplies, and through the continual renewal of the attack the action, small in itself, attains high values.

The chemical bonds of the silicate break down under the onslaught of the water, and there are formed, as a result of the simultaneous taking up of water, free molecules of bases and acids which are electrically neutral. This process is termed "hydrolysis." (The molecules of the acids and bases then dissociate further into electrically charged particles—the ions). Compounds possessing but slight chemical activity the so-called "weak" acids and bases, are liable to extensive decomposition by hydrolysis. The silicic acids are weak acids at ordinary temperatures.

The weathering of silicates may be regarded as taking place as follows:—*The silicate minerals are very slightly soluble in water, but traces do actually pass into solution. These silicate molecules in solution dissociate into cations of the metals present in the original compound and anions of the "silicic" group. The water itself is dissociated into hydrogen ions and hydroxyl ions, the degree of dissociation depending on the temperature. Now the weak acids are very feebly dissociated. Consequently the silicic ions are incapable of existing in the presence of the hydrogen ions; they combine with the hydrogen ions to form undissociated silicic acid,

* This account diverges slightly from that given in the original text. It seemed to the translator to be simpler when expressed in terms of the Ionic Theory.—(C. L. W.)

which separates out in the amorphous condition. The metallic ions unite with hydroxyl ions to form basic hydroxides, which remain in solution and for the most part dissociated into ions. This process is an example of "hydrolysis." The amorphous silicic acid forms a thin skin coating the mineral particles.[11] These coatings cannot be seen without further treatment, but may be recognised by staining with methylene blue or other suitable dyes. The film of silicic acid formed in this way checks the action of the water, since weathering can now only take place by the action of the water which diffuses through the skin. The rate of weathering becomes slower and slower, and leads to the formation of scales and crusts of weathered mineral which frequently surround a core of unaltered silicate.

The weathering of the silicates therefore depends in its very first stages on the action of water in the liquid state. It is therefore practically suspended at temperatures below the freezing point; it does not take place in frozen soil, or, as Lang says, using an expression borrowed from physiology, the soil suffers from "cold rigor."[12] Hence, it is only those periods of the year which are free from frost that are of significance for the progress of this type of weathering. The rapid increase in the chemical activity of water with a rise in temperature is of still greater importance.*

In the case of the widely distributed silicates containing aluminium, such as the felspars, micas, etc., it is probable that alumina and silicic acid combine to form complex acids (alumino-silicic acids) which behave in the same way as silicic acid. The first products of weathering are amorphous hydrated aluminium silicates, or "clay." As a result of the prolonged action of water, these compounds in turn are hydrolysed and

* If we take, as is permissible, the electrical conductivity of water at different temperatures as a measure of the chemical activity of water, and put the conductivity at 0° C. at unity, we get the following values:—

0° C.	10° C.	18° C.	25° C.	30° C.	40° C.
1	1·6	2·3	3·2	4·4	5·5

An arctic soil with an average temperature of about 10° C. and four months without frost would only be subject to one twentieth of the weathering that a tropical soil would experience with an average temperature of 30° C. and twelve months free from frost.

split up into aluminium hydroxide and silicic acid. It is generally accepted that the frequent occurrence of crystalline hydrated aluminium hydroxide in warmer countries, especially in the tropics, is due to the further decomposition of this clay. The decomposition of clay is a process which takes place extremely slowly; its dissociation products are only found in large quantities in the soil when the action of water has been intensified by a higher temperature. It is only within recent years that the presence of free alumina has been demonstrated in a number of soils of the temperate zone.[13]. It must not be forgotten in this connection that a serviceable reagent for free alumina is not known, so that it may be much more widely distributed in our soils, though in small quantities, than is commonly believed.

The iron present in silicates separates out in weathering, for the most part as ferric hydroxides. These compounds contain varying amounts of chemically combined water, and readily pass from one form to another by losing, and probably also by taking up, water.

The ferric hydroxides vary greatly in colour. As a rule those formed at lower temperatures and a comparatively low rate of evaporation are yellowish-brown to brown, those formed at higher temperatures with rapid evaporation are yellow to red. Apart from humus, iron compounds are the ingredients which are responsible for the colour of a soil; the differences in colour which they produce are often characteristic of the soils of different climates. Soils containing little or no iron are recognised by their lighter colours, white varying through grey to black as their humus content increases.

Chapter II

THE ACTION OF THE WATER CIRCULATING IN THE SOIL

The atmospheric precipitation consists of almost chemically pure water; in the soil it dissolves the soluble substances present and attains a state of equilibrium with those constituents on which it exerts a solvent or chemical action. Hence the liquid circulating in the soil is a salt solution whose concentration varies, but is usually very low.

The soil-water may be classified as follows:—

1. *Hygroscopic Water*, equivalent to the water content of air-dry soil, is retained by the surface forces of the soil particles. Its amount varies according to the vapour-pressure of the surrounding air. It is bound to the soil particles by powerful molecular forces.[14]

2. *Capillary Water*. By capillary water is understood that portion of the soil water other than hygroscopic water which, held by the forces of surface tension, does not drain away under the action of gravity. It evaporates if the air is not completely saturated with moisture.

3. *Gravitational Water*. That portion of the soil water which drains away under the influence of gravity.

There is no fundamental difference between capillary and gravitational water; they are only portions of the *free* water of the soil, in the movement of which either of the forces mentioned—surface tension or gravity—may prove decisive.[15]

The capillary water envelops all the soil particles with thin films and accumulates at the points of contact of the particles, so that its distribution in the soil corresponds to an equilibrium

of the forces at work. If this equilibrium is disturbed (by evaporation, absorption of water by plants, etc.), a new state of equilibrium, corresponding to the smaller quantity of water, is brought about by a flow of water towards the places from which it is being drawn. This adjustment takes place rapidly or slowly according to the thickness of the films; with very thin films the rate of flow may become so small on account of the viscosity of the water that the conduction of water practically ceases.

Water can therefore flow in any direction in the soil, the rate of flow depending on the capillary potential, size of the particles, etc. The downward movement, controlled by the action of gravity (descending current, percolation water) and the upward movement (ascending current) are most important. Gravitational water moves in the former direction, while currents due to evaporation at the surface of the soil flow in the latter.

The processes involved in the evaporation of water from the soil have not yet been worked out theoretically, and are very complicated.[16] The moist surface of the soil gives up water to the air in proportion to the saturation deficit, i.e. the quantity of moisture required to saturate the air. The rate at which this loss takes place is influenced by the temperature of the soil, the water-supplying power (conductivity) of the soil, intensity of the winds, and by the living plant covering. In addition to the external evaporation, an internal evaporation also takes place in the soil by the diffusion of water vapour into the atmosphere; this depends to a very large extent on the temperatures of the layers of the soil, and must vary with individual soils.[17]

Ground-Water. As a rule the formation of a water-table is explained as being due to the accumulation of gravitational water on an impermeable layer of the soil. This corresponds to the usual state of affairs, but in many cases is insufficient to account for all the circumstances. In the neighbourhood of Münich, for instance, a calcareous gravel overlies a fine-grained Tertiary sand known as "Flinz," above which the ground-water is found to accumulate. Now the Flinz from

its very nature is not "impermeable"; in spite of this it carries ground-water, and this is due to the heavy rain-fall of the Swabian-Bavarian plateau and the extremely high permeability of the overlying gravel. Ground-water will always accumulate if the quantity of water supplied from the overlying strata is greater than that draining away. It is a question of equilibrium between the additions of water and the drainage, no matter whether the additions are from an overlying stratum or from the atmosphere.

The Action of the Water Percolating into the Soil. Rain or snow comes into contact with the soil in the form of pure water, and in a very short time attains a state of equilibrium with those constituents of the soil which the water can dissolve or act on chemically. The next layer is permeated by a dilute salt solution. This can still dissolve any easily soluble substances that may be present, but has to a large extent lost its power of causing decomposition. Hence the soil is progressively leached, layer by layer, and its assailable ingredients decomposed. This process enables us to understand the frequent occurrence in very wet districts of leached strata, which have undergone intense chemical weathering, covering, often with sharply defined boundaries, layers which still contain large quantities of easily weathered material. Substances carried down to lower levels in solution are only separated out there as a result of chemical changes, not by crystallisation from the soil solution.

The solvent action of water is enhanced by the presence of carbonic acid. The quantity of carbonic acid present in solution is determined by the carbon dioxide content of the surrounding air; the carbon dioxide content of the soil atmosphere rises considerably in most cases with increasing depth. The carbonates of calcium and of magnesium are soluble in water containing carbonic acid as a result of the formation of the acid carbonates. The concentration of the solution corresponds to the state of equilibrium between the acid carbonates and the amount of carbon dioxide dissolved in the water, which in turn depends on the carbon dioxide content of the surrounding air. Calcium carbonate separates out from

a soil solution if the carbon dioxide content of the surrounding air decreases and so disturbs the equilibrium.*

The conditions are specially modified by the presence of substances in an extremely fine state of division dispersed in water, i.e. in the colloidal state. In the soil, clay and humus are of the greatest importance; both are amorphous and pass more or less readily into the colloidal state. The effects produced by humus have not yet been satisfactorily elucidated, one is frequently restricted to comparison with better known colloids.[18] Colloidal solutions of humus (humus sols) are found in soils that are deficient in salts, especially those of calcium, and in soils containing sodium carbonate (soda).

The soil solution in soda soils rich in humus is dark in colour, often as black as ink; on dialysis silicic acid and ferric hydroxide remain from the mineral portion. In soils that are very poor in salts, the humus substances are dispersed; the drainage waters, and also water flowing off the surface, appear more or less dark in colour when examined in thick layers (Black water), and form a great contrast with the clearness of calcareous waters.

Under the influence of humus sols ferric hydroxide and phosphoric acid become soluble, or at all events mobile, in the soil so that they may be removed by the percolating water, and for the most part are separated out again at lower levels (Pan formation). In this way the upper strata are deprived of iron, and as a result of the loss of their colour-giving ingredient, are bleached (Bleached Soils).

The range of the solvent action of water varies according to circumstances. This may be summarised as follows:—

* The action of sodium carbonate on calcium sulphate also results in the deposition of calcium carbonate in the soil. The reaction is reversible, its course being determined by the carbon dioxide content of the surrounding air. It may be expressed in a simplified form by the following equation:—

$$Na_2SO_4 + CaCO_3 \rightleftharpoons Na_2CO_3 + CaSO_4$$

If little carbon dioxide is present the reaction proceeds from left to right; if much carbon dioxide is present, it proceeds from right to left. This reaction is of importance in arid districts and with a high concentration of the soil solution.

1. *Soluble in pure water*: all chlorides and nitrates, the sulphates of the alkalies and of magnesium, the alkaline carbonates. Calcium sulphate (gypsum) is moderately soluble (one part in about 400 parts water).
2. *In water containing carbon dioxide*: in addition the carbonates of calcium, magnesium and ferrous iron.
3. *With the aid of humus sols* the following become soluble or at least "mobile": ferric hydroxide, aluminium hydroxide and phosphates.
4. *Under the action of humus sols in the absence of air* (oxygen), ferric hydroxides may be reduced and dissolved as ferrous carbonate.

The Action of Ascending Currents of Water.

From the foregoing discussion, we see that the rainfall reaches the soil in the form of pure water which is only changed into salt solutions in the soil. The percolating water together with that portion of the ground water out of the range of the capillary action of the upper layers of the soil continually removes larger or smaller quantities of substances from the soil. The soils are "leached." The ascending current works in opposition to leaching. The composition of the ascending current amounts to a dilute solution of salts. In order to transport equal quantities of salts a much feebler movement of water is required in the upward direction, as a rule, than in the downward. This is especially evident if the soil water is raised from greater depths since it is then much richer in soluble carbonates. It must be borne in mind in connection with this phenomenon that the composition of the soil water corresponds to an equilibrium between the soil, the quantity of water and the soil atmosphere. Hence the salt content can vary considerably at different levels. As a result of continued evaporation the solution becomes more concentrated in the upper layers; constituents which were stable when in contact with the air rich in carbon dioxide found in the lower levels, become unstable in the air of the upper levels which is poor in carbon dioxide, decompose and are separated out.

The most important processes are:—

1. *The soil solution attains the crystallising concentration; the dissolved substances crystallise out.*

An example of this phenomenon is afforded by the efflorescense of very soluble salts on the surface of the soil in very dry regions; more especially sodium chloride (common salt), sodium sulphate (Glauber's salt), magnesium sulphate (Epsoms salt), also sodium carbonate (soda) and nitrates; calcium chloride remains in solution on account of its high solubility and affinity for water. If the soil water contains salts which are only slightly soluble such as calcium sulphate, the concentration necessary for crystallisation is reached in the deeper layers of the soil, and strata are then formed which are rich in calcium sulphate (the gypsum horizon, e.g. in the Black Earths of Eastern Europe), or, if separation first takes place at the surface, gypsum encrustations.

As a rule the crystallising concentration of solutions of calcium sulphate is attained before that necessary for the decomposition of calcium bicarbonate. The gypsum horizon of a soil therefore mostly occurs at lower levels in the soil than the calcium carbonate horizon. A higher content of soluble salts increases the solubility of calcium sulphate considerably, so that gypsum rises to higher levels in saline soils than in soils having a low salt content. In moist regions the percolating water washes out the sulphates, so that deposits of gypsum in horizons are restricted to arid regions.

The fact that the deposition of salts takes place for the most part in definite layers of the soil—horizons—is due to the circumstance that, on the whole, similar conditions recur annually. Crystallisation and decomposition of the constituents of the soil solution will therefore take place at approximately constant levels. The horizons vary greatly in thickness; they may be restricted to a few inches or may even attain many feet. This applies particularly to deposits formed by the decomposition of dissolved substances. As a rule the limiting factor is the aeration of the soil, the extent of which is altered by the deposits, since these consolidate the soil and

hinder the entry of atmospheric air. This may lead to the formation of large layers and bands, which, commencing at low levels, gradually reach higher and higher levels until finally they reach the surface of the soil, where encrustations are formed.

Under certain conditions a pan may be formed by the crystallisation of readily soluble salts. Salts are dissolved, until the saturation point is reached, by the scanty rains, the solution trickles down to lower levels, and the upper layer of the soil remains comparatively free from salts. The Americans call this type of pan "Alkali hard-pan."[19]*

An important way in which the ascending current is furthered is by the absorption of water by plants, since these consume large quantities in their vital processes. Absorption is effected by means of the roots; the greatest concentration of salts will coincide with the most extensive distribution of the roots. Careful investigations on this action of vegetation on the soil are highly desirable

2. *Deposits formed by the Decomposition of dissolved Substances.*

It is probable that decompositions of substances dissolved in the soil waters are almost entirely restricted to the carbonates.

The most important decompositions are:—

(1) Calcium bicarbonate to calcium carbonate, water and carbon dioxide, the calcium carbonate being deposited. The acid salt (bicarbonate) is much more stable than the corresponding salt of magnesium. Deposition takes place comparatively slowly.

(2) Magnesium bicarbonate to magnesium carbonate, water and carbon dioxide.

(3) Ferrous bicarbonate to ferrous carbonate, water and carbon dioxide. In the presence of atmospheric oxygen the ferrous carbonate decomposes with the absorption of

* The presence of a eutectic mixture may also play a part in the separation of these saline layers of the soil.

oxygen, and is converted into ferric hydroxide with the liberation of carbon dioxide.

(4) Manganese bicarbonate to manganese carbonate, water and carbon dioxide. Manganese carbonate is apparently more resistant in air than in the soil, where, as it seems, it is converted into manganese dioxide by the activities of micro-organisms.

The precipitation of the carbonates of calcium and magnesium takes place as a result of the lower carbon dioxide content of the surrounding air (limit of aeration); the formation of ferric hydroxide follows on access to atmospheric oxygen.

The precipitated carbonates may cement the soil to solid rocks, or form concretions, or be deposited in fine grains between the soil particles.

In decidedly moist districts the calcium and magnesium content of the soil is greatly reduced by leaching, and is too low to form horizons; in moderately moist districts, however, calcareous deposits may be formed locally, while, in arid regions, they are of widespread occurrence. The better the soil is aerated, the greater the depth at which the calcareous horizon is formed, so that it is influenced by the penetration of the roots of plants into the soil. Coarse-grained strata of the soil, especially beds and bands of gravel, facilitate the deposition of calcium carbonate since they permit free movements of the soil air.*

Entirely different conditions are required for the formation of deposits of ferric hydroxide from the soil solution. The assumption is that, in the soil, conditions are such as to render the iron soluble, this requirement being fulfilled by the presence of easily oxidisable organic substances (humus), which occur, as we know from experience, through lack of aeration at low

* The distribution of calcium carbonate enables us to differentiate between leaching of calcium carbonate by the downward current of water and deposition by the ascending current. In the first case the content increases, as a rule, with the depth; in the second case a layer rich in calcium carbonate is found superimposed on one poor in calcium carbonate. It must be remembered that dissolved salts are very rarely deposited in lower layers of the soil. This can occur, for instance, in the case of calcium carbonate, in beds and pockets of gravel if these are in contact with the air at any place, so that they are well aerated.

levels, or through the slow decay of the remains of organisms. The statement that humus can reduce ferric ions but not ferric hydroxide is only relatively correct. The fact that ferruginous waters, especially ground water, are always found where organic remains are present in deeper, not aerated or only insufficiently aerated soils explains the assumption of the reduction of ferric hydroxide. The movement of iron in the soil requires further investigation.[20]

The requirements for the formation of iron deposits in the soil are fulfilled under very different climatic conditions. They are as widely distributed in the cool regions as a result of the slow decay of organic matter as in warmer ones with dense vegetation and heavy precipitations.

The deposition of iron often results from the vital activities of lower organisms, especially bacteria (iron bacteria). Practically nothing is known as to the occurrence and activities of these organisms in the soil, however, especially in the lower layers. It is to be assumed that biological influences play a great part in the deposition of iron in drainage waters; in the soil, on the other hand, chemical and physical processes probably predominate.

The distinctive characters of the iron deposits vary according to the conditions; there may be distinguished:—

(1) *Limonite,* Bog iron ore, Meadow ore etc. Banks of limonite or concretions with a rough jagged surface are formed where chalybeate springs emerge at the surface of the soil.

(2) *Ironstone Gravels.* Concretions having a smooth surface. The requirements for their formation are still unknown. Such gravels are widely distributed in the tropics.

(3) *Ochre.* Deposits of ferric hydroxide in a fine powder.

(4) *Deposition of ferric hydroxide between the soil particles.* It may occur as a cement binding the soil particles together (ferruginous sands, etc.), or may be mixed in varying quantities with the usual soil constituents. The formation of Laterite and Terra-rossa are special cases which are probably best classed under this group.

(5) *Surface water containing iron.* With low or moderate evaporation (perhaps also with a low content of iron compounds in solution), the ferric hydroxide is distributed irregularly in the soil, and above the water-table. Under most conditions the iron may form streaks and veins rich in iron (Bog Soils), or the movement of the ferruginous water may take place along cracks in the soil (Meadow Soils), or may be mainly restricted to the roots and root-stocks of the living and dead plants, which then frequently become encrusted with ferruginous deposits (e.g. in the Sump Soils of marshes).[21]

So far, but little is known concerning deposits of aluminium hydroxide in the soil. Until quite recently alumina was generally considered to be the most stable and immobile constituent both of minerals and of the soil, so that in calculations the aluminium content was used as a basis. The crystalline aluminium hydroxide found in Tropical Soils is generally (and probably correctly) regarded as a residue from weathering. Further investigations on the formation of iron pan have afforded definite examples of the translocation of aluminium hydroxide in the ionic or in the colloidal condition, apart from some soils which contain alum. Here we can only mention this process, which under certain conditions results in the formation of considerable deposits of aluminium hydroxide.[22]

Another unsolved problem is that of the fate of the silicic acid which is dissolved in weathering or is separated out as a colloid. Amorphous bodies, staining deeply with dye-stuffs, are often found in the soil, which are most probably correctly regarded as being silicic acid gel. On the other hand, the weathered soils of the tropics are so poor in soluble silicic acid that quite rightly the question is raised as to the fate of the considerable quantites of silicic acid which must be set free during weathering. The possibility of the separation of silicic acid in the soil in the crystalline form, as quartz, must be admitted; we have, however, no evidence of this action taking place on a large scale. For the present it would appear best to maintain that the soluble silica is leached out and carried

by the rivers to the sea. The problem can only be solved when a suitable method for the analytical determination of soluble silicic acid is found.

3 *The Formation of Humus.*

The dead remains of plants and animals accumulate in the soil, so far as they are not completely decomposed to carbon dioxide, water and ammonia or nitric acid. These intermediate products of decomposition are termed "humus."

The processes of its decay are almost entirely due to the vital activities of organisms, and these are dependent in turn on the temperature, water content, access of oxygen and the supply of nutrient mineral substances. According to the abundance or otherwise of the essentials for bacterial life, the dead remains are more or less completely decomposed. The accumulation of humus in a soil is governed by the quantity of organic matter and the rate of its decay; so here again we have an equilibrium which under average conditions for a given soil will lead to an average humus content.

The forms in which humus is deposited may be classified in three or four groups[23]:—

1. *Peat*:—Compact masses that may be cut, the plant structure visible to the naked eye. Varieties of peat differ in their properties according to the species of plants from which they have arisen. The following may be distinguished: —*Carr* or *Forest Peat* (predominantly the remains of trees), *Fen Peat* (remains of the vegetation by which water surfaces have been converted into land), *Moss Peat* (consisting mostly of the remains of mosses, etc.), etc.

Peat forms distinct types of soil, and also exercises a powerful influence, particularly when formed on a dry soil, on the properties of the underlying mineral soil.

2. *Mould*. A finely-fibrous form of humus arising as a result of mechanical actions, especially the burrowing and digging activities of animals and the penetration of plant remains by roots; the organised stıucture is still visible under the microscope, but to the naked eye it appears as an amorphous black, spongy mass.

3. *Dung.* The excreta, more or less definite in shape, of terrestrial animals.

4. *Humus substances having no recognisable plant structure dispersed amongst the mineral portion of the soil.* These mixtures cannot be separated mechanically, but by chemical means they may be divided into their two principal constituents, and display many of the properties of precipitates. This is the form in which humus is found in our heavy Arable Soils, in the Black Earths, etc.

Humus ranks as one of the principal factors in the formation of soils, on account of its influence on the properties of the soil as well as on account of its effect on the development of vegetation.

The dependence of the formation of humus on climatic conditions is obvious, since both the formation and decay of organic substances is due to the activities of organisms.

The accumulation of humus in the soil is determined by the quantity of organic matter synthesised by plants, as well as by the limitation of its destruction. As a rule there is an approximate equilibrium between the amounts of organic matter built up and broken down, so that the quantity of humus remaining in the soil is small. The conditions which delay the decay of humus are mainly low temperatures and dryness of the soil, i.e. periods of drought.

These relations can perhaps be best summarised by two examples:—

In the boreal zone the quantity of organic matter formed is small on account of the short vegetative period and the long period of frost, nevertheless, humus accumulates in large quantities, since its decay takes place more slowly than it is built up by plants. The soil in these districts over large areas is covered with peat formations. In cool temperate zones, especially under the influence of a maritime climate, the accumulation of humus, chiefly in the form of peat, attains the greatest dimensions on the earth. In the medium warm temperate zone the accumulation of humus as peat takes place almost entirely under water (Fen), the lower mean

temperature of the water is here to be regarded as the cause of the retarded decay of the organic matter.*

In the Black Earth districts large quantities of humus accumulate in the soil, intimately mixed with the mineral portion; here we have high evaporation during summer and long-continued frost during the cold portion of the year. The soil suffers greatly from drought, the luxuriant spring vegetation quickly uses up the moisture collected in the soil during the cold season. Drought in summer and frost in winter retard decay, so that humus accumulates in the soil. The requirements for the accumulation of humus in sub-tropical soils (Black Earths of Morocco, Southern Prairies of North America, Regur) have not yet been studied.

Tropical Soils are generally poor in humus. Decay of organic matter without the deposition of appreciable amounts of dark humus appears to be the rule in dry regions with high temperatures.[24]

Local Soils

The *major factors* involved in the development of soils are manifestly climatic; every soil owes its characteristics to a larger or smaller extent to the climate. In addition to these *major factors*, mostly affecting large areas, there are factors which alter the properties of a soil to a considerable extent, but which, nevertheless, are only topical in nature, even though they may affect considerable areas. The nature of the parent rock falls in this category; for instance, a very fine-grained granite, poor in felspar, gives rise to a shallow poor sandy loam, having a low content of the finer particles, while from a coarse-grained granite, rich in felspar, a deep heavy loam will be formed. The influence of the parent rock is clearly seen, but this only holds good so long as the character of the rock does not change. When we come to consider soils from the point of view of utilisation, those factors which only locally influence soil formation are of the greatest importance.

* For an alternative explanation see Clements, F. E. (1921), *Aeration and Air Content, The Role of Oxygen in Root Activity.* Carnegie Inst. Pub. No. 315.—(C. L. W.)

On this account they have received so much attention that the fundamental influence of climate has only obtained a tardy recognition, and even now has to fight for its position.

"Local" Soils are characterised by the possession of properties due to the action of locally acting factors. These distinctive properties of the soil are "permanent," i.e. they do not change within measurable time. In this way a distinction is made between Local Soils, and, on the one hand, soils whose characters are controlled by climate and on the other hand, from soils which obtain their character from organisms. Local soils are climatic Soils whose most important properties may be modified by local influences, but are still present.

The most important of these locally restricted factors are:—

1. The parent rock.
2. Texture, i.e. grain-size of constituents.
3. Situation.
4. Position with regard to point of origin of the minerals present, that is, whether sedentary or transported.

1. *The Influence of the Parent Rock on Soil Formation.*

The nature of the parent rock exercises the less influence, the more extreme the climate. In Eastern Europe Loess, Clays, Granite and Limestone are all uniformly covered by the Black Earths. The more temperate the climate the greater is the effect produced by the parent rock on the soil properties, both chemically and physically.

Rocks vary in their susceptibility to weathering according to their chemical composition as well as to their physical properties. The mode of formation of solid rocks has a marked effect, the greatest differences being shown by the massive rocks and the conglomerates. Coarse-grained, porphyritic or schistose rocks, even if they have the same chemical composition, each give rise to different types of soil. Properties which affect the penetration of the rock by the weathering agencies also aid soil formation. In the case of the Sedimentary rocks, the texture and the nature as well as the amount of the cementing material frequently determine the type of soil

formed. In loose unconsolidated masses the chemical and mineralogical composition is of importance, as well as the texture.

As regards the chemical composition of rocks, two constituents are of especial importance, silicic acid (including quartz) and the earthy carbonates, particularly calcium carbonate.

Quartz scarcely weathers at all, it only breaks into smaller fragments. The silicic acid content of rocks influences the rate of weathering, which on the whole makes the more rapid progress the less silicic acid the rock contains. In the soil, quartz and silicic acid serve to dilute the other ingredients; hence we may well speak of the non-quartz portion of the rock, since it is from this that the finest constituents—the clays—arise.

The influence of the earthy carbonates, particularly of calcium in the soil, mainly depends on the fact that weathering in the presence of calcium cannot result in the formation of soil ingredients having an acid reaction. Even the weakest acids decompose carbonates and liberate carbonic acid, which splits up into carbon dioxide and water and is removed from the soil. Hence soils containing carbonates do not give an acid reaction, but are usually slightly alkaline. Compounds of calcium have a potent flocculating action, so that Calcareous Soils are friable. When calcareous rocks are weathered, calcium carbonate is leached out, and those portions of the rock remain which do not consist of carbonates; the great variation in the Calcareous Soils (Chalk Soils) of moist districts is brought about in this way. The formation of humus proceeds somewhat differently on Calcareous Soils as compared with the process on Silicate Soils. The humus is very dark in colour and appears to decay but slowly; colloidal humus bodies which swell greatly on imbibing water are not found in soils rich in calcium compounds. If we bear in mind the very great probability of the presence of extensive fissures in the underlying calcareous rocks, and the resultant excellent drainage, we can see why soils with a large calcium carbonate content carry distinctive characters in all moist districts, and

are distinguished as Chalk Soils. In arid districts all soils have a sufficient calcium content to acquire the character of Chalk Soils.

Amongst botanists different opinions have prevailed for a long time as to the significance of calcium carbonate as affecting the distribution of plants. It is seldom remembered that a moderate content of calcium carbonate, from experience 2 per cent. to 3 per cent., is sufficient to give the soil enough calcium carbonate for chemical action; and that easily decomposable calcium silicates behave in the same way as the carbonates. So far as chemical actions are concerned it is of no significance whether 2.5 per cent. or 25 per cent. calcium carbonate is present.

The *Loess* Soils are widely distributed and cover an appreciable proportion of the earth's surface. They are remarkable for their uniform fine texture and their porous structure. They are Dust Soils, free from coarse rock particles and poor in clay. Both texture and structure of Loess facilitate the movement of water; water percolates readily, and rises quickly and easily from lower to higher levels. This behaviour depends on the long capillary tubes as well as on the fact that the movement of water is most rapid with a texture (grain-size) corresponding to that of Loess. (With larger grains the rise is very rapid, but the height attained is small; with a very fine texture the height attained is great, but the rate of movement is greatly reduced as a result of increased friction).

Although Loess is so widely distributed, its properties remain very constant; it is distinguished as a Local Soil, since when weathered it gives rise to different soils according to the climatic conditions.

The influence of the parent rock on the type of soil formed is most pronounced in regions of moderate weathering and temperate climate. It is not surprising that Fallou, who lived in Central Germany, based his classification on the parent rock; this was the first attempt to classify soils scientifically.[25]

The recognition of soil types according to the parent rock

is often of great value as regards the utilisation of the soil, and this is the greater the more uniform the formation, and the more widely it is distributed. An alteration in the climatic conditions is always accompanied by a change in the character of the Sedentary Soil formed from a rock. A Granite Soil in the Brown Earth region of Central Europe will have, roughly, the following characters:—a loose sandy loam to a loam with comparatively large quantities of potash, moderate amounts of phosphoric acid, low in lime; the formation and decay of humus taking place normally. In the regions of the Northern Bleached Earths from a granite of the same composition we should expect to find a compact Leached Soil free from compounds of iron and decidedly sandy in character, with a low content of plant nutrients, and in regions of heavier rainfall having a distinctly "podsol" profile (see page 68). Organic residues decay but slowly so that the ground is frequently covered with accumulations of only slightly decomposed humus.

A Basalt Soil of the Brown Earth region would be a Stony Clay Soil, well drained on account of the jointing of the rock, rich in plant nutrients, and so on.

A division of soils into Sedentary (Residual, Primary, Eluvial) and Transported (or Derived) has frequently been made the basis of the classification of soils. This separation is justified as regards Local Soils, but not as regards soils considered as a whole; for the loose unconsolidated rock formations succumb to climatic weathering in the same way as the solid rocks.

Transported Soils or Detrital Soils include those types in which the rock débris has undergone a change in position. The removal of the rock fragments from the place of disintegration and the redeposition of the fragments may be brought about by the action of gravity (screes, talus cones, etc. on slopes), by water (Alluvial Soils), by ice (Glacial Soils), or by wind (Sand Dunes, Loess), etc.

These soil types have definite properties by which they can be recognised. Almost all Transported Soils are deep soils, and as they are mostly deposited in the hollows of the land,

they usually have a sufficient or even an abundant supply of water.

Talus slopes and cones form very steeply inclined, loose piles of rock fragments of all sizes, the larger ones, up to boulders, predominating.

Alluvial soils, transported and deposited by the agency of water, are frequently to a large extent assorted according to the size of the grains and are then distinguished as Clays, Sands, Gravels, etc. Deposition mostly takes place at low levels in the form of flat beds. The composition of the soil varies according to the nature of the original rock, so that numerous sub-divisions can be made which are frequently given special names.

Soils of glacial origin cover very large areas in the Northern Hemisphere; they are deposits formed during the Pleistocene Ice Age. Glacial Soils fall into two large groups, those in which the moraine material carried by the ice has been preserved more or less unaltered, and those in which the fragments have been re-sorted by water. In this way, the Moraine Soils, consisting of a mixture of fragments of all sizes, from the finest rock flour to very large boulders, are distinguished from the Fluvioglacial Soils which have been re-sorted by the water from the melting ice. The latter consist mostly of deposits of sand and gravel, silts and clays being less common.

Deposits arising from the transport of rock particles by the wind are divided into two groups according as their grain-size corresponds to sand, or dust respectively. Aeolian Dust Deposits may be further divided into classes, viz. Loess and Volcanic Ashes.

2. *Grain-Size of the Soil Constituents.*

The usual classification of soils as Sands, Loams and Clays adopted both in Agriculture and in Forestry is really based on the composition of the soil in terms of mixtures of grains of different sizes. Grains of all sizes, from amicroscopic particles to boulders, take part in the structure of the soil. As a result of International agreement the grain-sizes have been classified

into the following groups (on the recommendation of R. Atterberg.[26])*

More than 2mm. in diameter:—*Stones*, which are further divided into:—Boulders (more than 10 cm. in diameter) and Gravel, i.e. Pebbles if rounded or Dreikanter if tetrahedral.

From 2 mm. to 0·2 mm. in diameter:—Sand

From 0·2 mm. to 0·02 mm. in diameter:—Fine Sand (Mo)

From 0·02 mm. to 0·002 mm. in diameter:—Silt (Schluff or Staub)

Less than 0·002 mm. in diameter:—Clay.

Each of these fractions exercises a definite effect in the soil. Stones influence the movement of water and the specific heat of the soil. Sand acts as a diluent of the finest ingredients and facilitates the entry of water into the soil. Silt exhibits powerful capillary actions and influences the ascent of water. The greater bulk of the products of chemical decompositions brought about by weathering are collected in the clay fraction; the particles of clay are in lively Brownian movement when suspended in pure water.

In most cases soils are mixtures of particles that vary greatly in grain-size. If these are approximately balanced, the soil is called a loam, if any one fraction predominates so as to impart its specific character to the whole, the soil is spoken of as a Sand, Silt or Clay as the case may be.

The classification of soils according to their mechanical analyses affords a means of representing definite properties of the soil.[27]

3. *Situation.*

Situation is a factor which influences the properties of a soil and is often of great economic importance; it is understood to include the height above the neighbouring surroundings as well as the slope and aspect or exposure. The absolute height or elevation (altitude) may lead to an alteration of the prevalent climate and consequently to the formation of

* This differs slightly from the classification in general use in England.—(C. L. W.)

distinct types of soil; these are most correctly considered in connection with the climatic soil types of different regions.

The angle which the surface of the ground makes with the imaginary level surface of the earth is known as the inclination or slope; the aspect or exposure is the point of the compass opposite a slope.

The angle of slope is expressed in degrees and affects the utilisation of the soil (agriculture is no longer possible with slopes exceeding 20°, and regular forestry with those exceeding 30°). Steep slopes suffer from the facilitated removal of the finer ingredients and from the surface off-flow of the water supplied by the rain and snow.

Aspect exercises a strong influence on the soil temperature and evaporation as a result of differences in radiation. At the same time the action of the prevalent winds comes into play and this tends to raise or lower the temperature and to decrease or increase the evaporation greatly. Influence has also been ascribed to the mechanical action of rain driven by the wind; slopes exposed to driven rain lose more earth by denudation than the soils on the leeward, sheltered side.

The insolation of slopes, and consequently their warmth, varies according to the aspect, so that large differences are displayed between Northerly and Southerly exposures. The action of the prevailing winds is scarcely less marked, so that on the borders of climatic soil zones it is not unusual to find regularly recurring differences in the soil type on the sunny and shady sides.

These effects may become so great as to give rise to special types of soil which are peculiar to slopes and to the freely exposed surfaces and peaks of mountains, and which may be termed "Reef Soils" (Randböden). A good example of this type is afforded by the very loose Black Soils, containing large quantities of humus, of the limestone hills of southern Germany, which have recently been described and investigated by Höfle.[28] It is probable that the Terra-rossa of the limestone slopes in the North Mediterranean regions should most correctly be included in the group of Reef formations. Exceptional types of soil formation will reach their highest state of

development on fissured rocks, which not only provide rapid drainage but also promote the dessication of the soil by preventing the supply of water by the ascending current. Hence, it is not surprising that the formation of these exceptional Reef Soils occurs on calcareous rocks in particular. Up to the present very little attention has been given to these Reef Soils; it is quite likely that they are of much more frequent occurrence than is generally supposed.

4. *Fixity of Soils. Shifting Soils.*

Most soils are sedentary, i.e. they remain at the place of their formation and undergo progressive weathering. Changes of position of the constituents rarely occur, or are confined to movements within the soil itself. In vertical section these soils present a characteristic appearance, a soil profile, from which the processes of soil formation can be recognised.

The formation of a soil profile requires a longer or shorter time according to the prevailing conditions. A necessary condition for the formation of a characteristic profile is that the soil must remain stationary for a sufficient length of time, i.e. its position on the earth's surface must not be changed by the action of external forces. Changes of position may take place rapidly or slowly. If the movement is rapid no recognisable stratification due to weathering will be present. The soil may then be uniform in texture (Dunes) or may show regular gradations in the sizes of the particles (e.g. Northern Flowing Earths). Soils which are in motion may be collectively called "Shifting Soils." If Shifting Soils lose their mobility and become fixed in position they undergo the weathering peculiar to their locality.

If the change in position takes place slowly, the soils are visibly attacked by the progressive weathering, but removal takes place too quickly to admit of the formation of a profile corresponding to the climatic conditions; soils of this type may be termed "Creep Soils." Such creeping soils are frequently found on mountain slopes in many moist districts.[29] It is probable that they are widely distributed on mountains in the tropics; the rapidity of weathering and the heavy

rainfall would lead one to expect the formation of Creep Soils, and the usual steepness of the sides of mountains in the tropics are evidence of their presence.

Creep Soils are often composite in character and consist of residues of the different strata which build up the slope. The Alluvial deposits (Abschlämmassen) of the Geological Survey correspond to a transition between Creep Soils and soils transported by water.

In moist districts, to which Creep Soils are almost entirely restricted, an appearance is not infrequently presented that can easily be misinterpreted. The rate at which Creep Soils move is very small, so that the fact that they are in motion has only recently been recognised and received due consideration.[30] Frequently the weathering of the soil has apparently taken place without resulting in the formation of a soil profile corresponding to the climatic conditions. The profile is only seen where the configuration of the country has greatly retarded or stopped the movement. The almost complete weathering of the silicates in the upper layers of the soil, transformations of the soil by humus and the like are extremely slow processes, so that denudation of the layers often takes place more rapidly than does the transformation of the soil corresponding to the climate. In this way in a leached district the soil acquires properties that would lead one to believe that it was under the influence of a warmer climate than that prevailing. Soils in the Mittelgebirge of southern Germany often have the character of Brown Earths, though from the climate one would expect the formation of Bleached Soils, which are actually found in places where the movement is retarded.*

* The fact, that geologically young soils only after a long time acquire the full character of the climatic soil type, has induced Glinka to assign most of western and central Europe to the Podsol region, and to identify the Brown Earths with the "B" horizon of the Podsol soils. The "A" horizon is the layer of Podsol soils to which complete weathering and leaching has progressed, "B" is the layer of the soil in which weathering is in active progress and which has been enriched by the precipitation of dissolved substances from the "A" horizon by the chemical (colloidal) transport of ferric oxide and alumina. According to Glinka, the Brown Earths are immature Podsol soils, but they lack the leached horizon "A" so far as sesquioxides are concerned, and the enrichment horizon "B." The Brown Earths occupy an intermediate position among soil types in correspondence with

To the group of Shifting Soils must also be assigned the Flowing Soils of the North; these soils are maintained in continual motion by the deflocculating action of water which is free from electrolytes and by the volume changes resulting from the freezing of water.[31]

The Flowing Soils merge into the silty Quick Sands and fine Sandy Soils which begin to flow when saturated with water. These soils correspond to the "Moving Mountains" of mountain peasants; they are distinguished by the water present not flowing away, even when it is given an opportunity of doing so. These soils are not crumby, but have a single-grain structure.[32]

Soils receiving continual additions of material.

From Shifting Soils it is most appropriate to proceed to a consideration of those soils to which material is continually being added from external sources. The additions are brought about by the agency of the wind or of running water.

Transport by wind is of no significance in moist districts, the drier the climate the greater it becomes. At the present time the regions lying to the East of the large deserts in the interior of Asia probably receive the largest quantities of wind-blown dust. Isolated dust-falls occur in all regions. In Europe, dust from the Sahara has repeatedly fallen in considerable quantities.

The deposition of wind-blown dust is especially favoured by mountains whose ranges are arranged at right angles to the direction of the prevailing wind. The current of air is cooled as it is forced up the slope, and moisture is condensed.

the temperate climatic conditions of their distribution, on the moist cool boundaries they merge into the Podsols, on the dry they resemble the Black Earths poor in humus (often having calcium horizons), in warmer regions they resemble the Red Earths but without losing the character of an independent soil formation. Naturally this does not exclude the occurrence in the Podsol region of soil varieties which accord with Glinka's assumption and which are frequently not unlike the Brown Earths, especially if the feebly developed horizons "A" and "B" have been mixed by cultivation. Regular manuring and cultivation of the soil brings about a condition of the soil that approaches that of the Brown Earths. Man creates a warmer soil climate for this soil by his interference and counteracts leaching by manuring.

The dust particles floating in the air serve as nuclei for the formation of droplets of water and in this way get carried to the ground with the mist, rain or snow. Treitz has recently demonstrated the importance of wind transport for the soils of the Carpathians.[33]

A similar state of affairs is found to favour the deposition of dust by river valleys as by mountains. Here the prevalent local winds (valley and mountain wind) create similar conditions for the separation of the wind-blown dust as in the case of mountains. By this means broad river valleys often become the boundaries of soil types; the Post-Glacial deposits of Loess, which frequently follow the course of the rivers in Germany, were probably due to these effects.

The conveyance of sand and dust by the wind in districts having active volcanoes often attains enormous dimensions at times of volcanic activity. The soils of Central America and of the volcanic islands of the East Indies owe their special character to the additions of volcanic ashes, frequently in huge quantities; Mohr calls them "Efflata Soils."[34]

The conveyance of mineral particles by water at times of normal water-level usually results in the formation of banks of gravel and sand which are generally of a temporary nature and really form a sub-division of Shifting Soils.

In districts which are flooded regularly or at frequently recurring intervals, sand, silt and clay are deposited, with the result that the level of the soil is gradually raised (Warp Soils). The nature of river deposits varies in accordance with the rock formations of the drainage area and with the fall of the river.

Soils of a special type are formed at the coast under the influence of the tides on flat beaches. Such Mud Soils, for instance, when converted into dry land, form a large part of our marshes (Muck Soils). Mud Soils are formed in very different climates. Up to the present very little is known of these deposits outside Europe.

All the soil types considered in this sub-division have a mixed character, they undergo the prevalent weathering, but receive additions of foreign material which is mostly

unweathered. The soils will be characterised by minerals produced by the action of the prevalent weathering if the supply is cut off. Such a change may be brought about in the Mud Soils of marine marshes by reclamation (empoldering) or by the rise of the deposit above the average water level; in Warp Soils by the river changing its course, or by the soil being raised above the flood level; in "Efflata" Soils by a diminution in volcanic activity.

Appendix. Geological Age of Soils. Change of Climate.

Soil formation is a geological process which commences as soon as land is formed. Soils have been formed in all geological periods. The fact that the soil is built up of loose fragments and contains chemically decomposed organic substances is not favourable to a lasting preservation of soils. From the further consideration that Fossil Soils are altered by diagenetic processes (changes due to the decay of organic matter), and also that it is only recently that attention has been called to the occurrence of Fossil Soils, it is not surprising that the number of known instances is so small.[35] Soils which have been covered by Aeolian Deposits are easily recognised; in the neighbourhood of sand-dunes they are comparatively common. Russian investigators have introduced the expression "Buried Soils" as a cognomen for this type.[36]

The majority of soils of former periods have been removed and destroyed. Glaciers and inland ice may frequently have had but little effect as far as the removal of projecting masses of hard solid rock was concerned, but their erosive powers were doubtless sufficient for the removal of loose material. A large portion of the Northern Hemisphere was denuded of its old soils during the Glacial Period, and is now covered with soils which from a geological point of view are young. At the same time the Glacial Period was accompanied by great changes in climate so that not only the areas actually covered by the ice were affected, but also those areas free from ice were subjected to changes in the climatic conditions. The author is inclined to ascribe great importance to these actions so far as Central Europe is concerned. The piles of boulders of

the Mittelgebirge bear the impress, although only to a slight extent, of weathering by the freezing of water. The frequently extensive removal of clay from the higher levels implies the action of water free from electrolytes. The Sedentary Soils often show indications of having undergone intense leaching at that time. At the close of the Diluvial Period and after the Diluvial Period perceptible changes of the soils present have set in. The North-West boundary of the eastern European Black Earth is surrounded by a belt of Grey Forest Soils derived from previous Black Earths. These soils were called "Degraded Black Earths" by the Russian investigators.[37] Such soils stretch far towards the West; they are comparatively widely distributed in the lowlands of North Germany. The transformation of the Black Earth has probably been brought about chiefly by the disappearance of the forest. A forest covering will produce a different soil climate from that met with on a grass steppe. An alteration in the soil climate, due to a changed vegetative covering, seems to be adequate to bring about the formation of a different type of soil in the border regions.

For soils which have lost their original properties under the influence of a change in climate, the author has elsewhere proposed the term "Relic Soils" (Reliktenböden).[38]

CHAPTER III

THE ACTION OF ORGANISMS ON THE SOIL

THE soil is the substratum of terrestrial organisms. The relationship between the living organism and the soil becomes the more intimate according as a greater proportion of the life history is passed in the soil. A high degree of adaptation to the soil climate is then shown, especially to the soil atmosphere which is saturated with moisture. This adaptation is perfect if the organism is unable to withstand exposure to the ordinary atmospheric climate; this holds good, for instance, with many worms which live in the soil and die when brought to the surface on account of the intense evaporation which takes place from the surface of their bodies. Other animals only spend part of their life in the soil, e.g. the larval period, and their adaptation is therefore partial only. The higher plants show a double organisation, stems and leaves being equipped for the aerial climate, the roots for the soil climate.

Animals affect the soil by their burrowing and digging activities, by their excretions and by the demolition of living and dead parts of plants.

The transformation of the residues of plants into fine fibrous material is brought about to a large extent by animals. Their burrowing actions affect the soil mechanically and aid the formation of crumbs. The excrement deposited by terrestrial animals occurs locally in such large quantities, especially in soils having a large worm population, that the soil acquires a characteristic nature by this means.

Amongst animals, worms, particularly earth-worms, are the most important agencies in soil transformations; but all other animals exercise more or less influence.

Plants may be divided into a micro-flora and a macro-flora as regards their activities in the soil. The micro-flora includes bacteria, fungi and individual groups of algae.[39] This little world is the chief means by which the breaking down of dead

organic residues, with the formation of humus, is accomplished. Amongst the bacteria, numerous species and groups with specialised vital requirements and consequently specialised functions are met with, such as the nitrogen-fixing bacteria, the nitrate bacteria, the sulphur bacteria, etc. The vital activity of bacteria is very great for their size, and the enormous numbers in which they occur magnifies the effect produced. In this way, bacteria become one of the most important agencies in soil transformations. Fungi have still been but little investigated as regards their activities in the soil; though it may be assumed that the separation of dark coloured humus substances from dead plant remains is mainly brought about by these organisms.[40] On the whole, bacteria shun the light, and prefer soils rich in nutrients with a neutral or slightly alkaline reaction. Fungi differ in being able to develop luxuriantly on soils poor in nutrients and having a slightly acid reaction. In well aerated, crumby soils, rich in nutrients, bacterial life predominates; in compact soils, deficient in nutrients, the fungi are most conspicuous.

A great deal of investigation is still required as to the distribution and activities of soil micro-organisms In moist regions they are most numerous in the uppermost layers of the soil, the numbers decreasing rapidly at lower levels, the soil becoming practically sterile at a depth of 50 centimetres. In dry regions the bacteria reach a much greater depth, their presence having been proved in some Western American soils at a depth of several metres.

The plants belonging to the macro-flora supply, after their partial or complete death, the raw material for the formation of humus. Plants exercise a very great influence on the soil: they remove large quantities of water from the soil and thereby influence the movement and distribution of water and of dissolved substances in the soil. The permeation of the soil by the roots exercises a mechanical action, breaks up compact masses of humus and promotes the formation of compound particles (crumbs).

Closed formations of plants form a covering above the soil; they prevent direct insolation of the soil, reduce the

rate of movement of the air and protect the soil from the mechanical blows of the falling rain drops. All these actions influence the soil climate. It can be taken as a general rule that a covering of living plants reduces the maximum temperatures of the soil, to a large or very large extent, as compared with those of bare soils.

The effect of the vegetative covering becomes the more marked the thicker and more uniform the vegetation, and the longer the period of vegetative growth.[41]

Although each individual plant influences the soil, the effects only become conspicuous with plants growing together in harmony, in plant communities (formations, associations). The soil acquires definite peculiarities according to the prevalent plant covering, so that a close relationship is established between the plant kingdom and soil formation. Metaphorically, we may speak of a symbiosis between the plant covering and the soil—each influences the other. This holds good, not only for the higher plants, but for soil organisms in general. Not only are the members of a plant community inter-related, but the animal life of the soil and the world of micro-organisms assume different aspects under the influence and protection of the vegetative covering. All these organisms are members of a great community, all, through long periods of time, have become adapted to one another and to the properties of the soil, so as to give the impression of a single organisation whose members live in intimate association with one another and are dependent on one another for their existence.

These effects are seen to the best advantage in woodlands. In those countries which have an ancient civilisation forest and forest soils, as opposed to areas of arable and pasture land used for agricultural purposes, have suffered the least change under man's influence.

In comparison with other plant coverings the influence of the forest is very marked; this is the result of the two-fold cover—the fallen foliage and the canopy. In summer the temperature of forest soils is considerably lower than that of bare soils; the wind movement in the interior of close woodlands is negligible; both these effects reduce the evaporation

from the surface of the soil. The uppermost layer of forest soil is therefore, on the average, moister than that of bare soils, with the result that the development of the micro-flora and fauna is favoured, the breaking down of organic matter is accelerated and takes a more uniform course. The roots of trees have a long life so that they only contribute a trifling amount to the organic matter of the soil, the supply of dead residues being furnished almost exclusively by the leaf-fall at the surface of the soil. The admixture of the organic matter with the mineral portion of the soil thus depends on the activities of animals and plants. Different kinds of trees influence the soil to different degrees and in dissimilar ways, so that definite types of soil are found corresponding to the more important kinds of forest (Beech, Pine, Fir, Mixed Woods).

These relationships are still further complicated by the influence which lower coverings of the soil (mosses, grasses and other members of the ground flora) exert on the soil, and this exceeds that of the tall trees when the latter are scattered in open formation. Finally, the behaviour of the trees themselves varies with the climate. For instance, the beech is the most valuable tree, as a soil improver for the forests of Central Europe; under its cover the soils gain in fertility and animal life abounds. On the other hand in the coastal belt of the North-West of Europe thick beds of beech-peat arise in pure beech woods, and natural regeneration is not a success. Under a covering of pines the soil remains healthy, provided that the limits of the natural distribution of pines are not exceeded; in districts of greater evaporation the pine causes more damage to the soil than any other forest tree. The relations between plant communities and soils are very complicated and require thorough investigation.[68]

If the vital relationships between soil and plant community are destroyed by natural or artificial means, nature repairs the injuries inflicted, provided that they are not too severe. Should the injury persist for a long time the soil may assume a different character. Devastated forest soils are found in all countries and in all climates.

The following plant formations are of especial importance as regards temperate climates:—

1. *Forest.* The distinctive peculiarities of forest soils as compared with bare soils or soils covered with other formations have already been indicated, viz.: great lowering of the maximum temperatures, reduced evaporation from the surface of the soil and deposition on the ground of the dead portions of plants. The influence of the forest is so considerable as compared with that of a bare soil that the afforestation of a bare fallow field produces the same effect on the soil climate as would the removal of the field towards the North through several degrees of latitude.[42] Of the forest formations predominant in Europe we must mention the Northern Coniferous Forest (Type—Pine), and the Mixed Broad-Leafed Forest (Types—Beech and Oak). The most important of the lower coverings as regards their effect on soil properties are heather, herbs and mosses.

2. *Grassland.* This is characterised by the predominance of grasses of different kinds. There may be distinguished:—

   (*a*) *Meadow formations*, with grasses having a long period of growth, which, on account of their high water requirements, are restricted to districts having a heavy rainfall with slight evaporation or to soils supplied with water from below.

   (*b*) *Steppe formations* with grasses having a short period of growth. Steppes occur in a temperate climate in districts where there is a very great difference between summer and winter. In the cold season water accumulates in the soil (winter moisture), which suffices for the requirements of a luxuriant but short-lived spring vegetation.

   (*c*) *Savannah.* The soil is preponderantly covered by tall grasses having stiff, hard leaves. The vital relationships are similar to those found in Steppes; during and after the rainy season large quantities of water are available for the use of the plants.

(*d*) *Reed Swamp* may be mentioned as a forth type of grassland. This, consisting mostly of Cyperaceae, is the chief formation concerned in the conversion of lakes into dry land (Fens, Sour Meadows).

The enormous extent to which the soil is permeated by roots is common to all forms of grassland. Most of the roots die annually; hence the formation of humus mostly results from the remains of the roots, which penetrate more or less deeply into the soil. In the process of the conversion of lakes into land the portions of plants which project above the level of the water (reeds, sedges, etc.) succumb to the processes of decay, while the peat arises almost exclusively from the roots and rhizomes under water.

The formation of humus in the Prairie Soils and Black Earths is to be regarded as taking place in a similar way. Those portions of the plants exposed above ground either serve for the nutrition of animals, or decay; the numerous and deeply penetrating roots of the Steppe plants decompose slowly and give rise to the humus of Black Earths.

Thus we see that in the formation of humus there is a fundamental difference between Woodland and Grassland. In woodland the plant residues accumulate pre-eminently on the surface of the ground, whereas in grassland the admixture of the humus-forming roots of grasses with the mineral particles of the soil predominates.

Grassland humus, excluding the formation of peat under water, is in a very fine state of division and intimately mixed with the mineral portion of the soil. In woodland on the other hand, two types of humus are found, which are fundamentally different in character and in their behaviour towards the soil. The one is that found in "healthy" or "sound" (mellow) soil: under the influence of tunnelling and burrowing animals, and rapid processes of decay there are formed mixtures of humus and mineral particles; the humus content decreases from above downwards. The other form of woodland humus is the deposition of the plant residues in solid, coherent masses, which may be cut, on the surface of the mineral soil (dry peat,

wet peat). As a rule wherever dry peat is formed the soil deteriorates; it is the form in which humus occurs in "sick" forest soils.

According to the influence exercised by plants on the soil, one can speak of Pine-soils, Beech-soils, Pasture-soils, etc. As a rule these expressions are used in the sense of their suitability for these kinds of plants, but they also at the same time express definite soil properties.

Cultivated Soils. Great areas of the earth's surface have been brought into cultivation by Man, and their soils have been altered by Man's toil. The charactertistic features of human interference are regularly repeated cultivation of the soil and the addition of manurial substances.

Crops, especially cereals, occupy a special position amongst plant communities; they have not been evolved naturally, but have been created and are preserved by Man's activities. If our cereal plants were left to their own devices, they would vanish from the flora within a few years; without cereals the majority of mankind would perish of hunger. Hence between Man and the cereals there is a close relationship to their mutual benefit, in which the cereals are as much concerned as is Man. As a rule relationships of this kind are only considered from Man's point of view; in actual fact it is scientifically a case of symbiosis, which has arisen through the helotism (servitude) of one of the members.

Garden Soils may well be taken as representing the highest type of cultivated soils; the effects of human efforts are particularly conspicuous in these soils. Without reference to its orginal properties Man tries to transform the soil in definite directions, viz. uniform mixing of the soil constituents and establishment of good tilth; enrichment in organic matter by the addition of organic manures (dung). Both these operations are conducted with the object of creating the most favourable conditions for the growth of plants. In particular, we may emphasise the beneficial control of aeration and of the water supply so as to avoid both a shortage as well as an injurious excess. Cultivation raises the mean temperature of the soil; the addition of organic matter increases the humus content

and ensures a plentiful supply of readily available nutrients for the plant.

All these actions create favourable conditions, not only for the higher plants but also for the micro-organisms of the soil. The bacteria are especially favoured, their numbers and activities being very great in well treated garden soils. On the other hand Man's work does not favour the life of small animals in the soil; this is less pronounced in garden soils with their large additions of organic manures than in arable soils. In arable soils as a rule the soil fauna is considerably reduced, both in numbers and varieties, as compared with that of land covered with a natural wild vegetation. The necessity for cultivating arable soils once or several times a year is enhanced by the diminution of the number of the smaller animals. Man must replace part of their activities by his own efforts.

The decay of organic residues is accelerated in regularly cultivated soils, and under certain conditions may lead to a rapid reduction of the humus content of the soil; the cereals in particular have for a long time been known to agriculture as "humus destroyers." To what a great extent this can take place is proved by some American investigations which showed that after ten to twenty years of uninterrupted cereal cropping the humus content of a Prairie Soil had fallen to one half of that originally present.[43] In unmistakable Black Earths we know from a century's experience that many soils can yield cereal crops continuously without becoming exhausted.

A survey of the influence of organisms on the formation of soils shows that it is considerable and frequently of the greatest importance, especially from the economic point of view. The action, however, is bound up with the presence of definite organisms. If these perish through any extraneous agency—Man's activities are of the greatest significance—the nature of the soil is permanently changed, and it acquires fresh properties, unless Man for his own purposes, reproduces as an artificial environment the characters of the original soil.

CHAPTER IV

THE CLASSIFICATION OF SOILS

THE classification of soils pre-supposes a recognised system of nomenclature. Here we meet with a difficulty at the very beginning. We speak of kinds of soil, soil forms, soil types, and soils. It is obvious that the conception of species that has been evolved from the classification of living organisms cannot be applied in the same way to soils. But perhaps it will be permissible to speak of specific "kinds" of soil in the sense that by each "kind" we mean certain soils that have the same general build and that have arisen in the same way. The designation of the climatic soil forms has up to the present been based with very few exceptions on the colour of the soil, since this is an external character which is easily recognised. The voice of the people has already been active in this connection: expressions such as Red Earths, Terra-rossa, Podsol, Tschernosem, Black Land are derived from the colour of the soil. The application of colour distinctions is upheld not only by the conspicuity of colour as a characteristic feature, but also by the fact that investigators of all nationalities have used it as a distinguishing character. The expression Bleached Earth, for instance, implies that we are dealing with a soil from which all the iron has been removed; Black Earth indicates a considerable humus content, Brown Earth that the iron content of the soil consists mostly of brown hydroxides of iron—the form characteristic of humid climates—Red

Earths that red hydroxide of iron—the form typical of warm climates—is present. But at this point it must be recognised that similar colorations can and do occur with dissimilar types of soil.

Bleached Earths arise from the action of acid humus which is deficient in electrolytes as well as from the action of humus sols formed by soda. The number of Red Earths will probably be considerable as soon as Tropical Soils are better investigated.

It would be a pity to give up the designation of soils according to their colours, for that would involve the loss of a number of ideas associated in our minds with colour and affording valuable clues as to the origin and properties of particular soils.

Nomenclature and definitions are aids to the understanding; they are attempts to express in simple forms the knowledge which has been acquired. Hence we find the position and state of advancement of Sciences most clearly reflected in their terminology, and this also most clearly expresses the progress of a science. At the present time the naming of soils according to colour meets the requirements of Soil Science; it seems expedient to retain it provisionally and to leave a change of the nomenclature to the future. We shall therefore retain the present nomenclature, but apply it in such a way as to express *general* properties. The colour names of soils must be re-defined to cause them to rest on a climatic basis so that they have more than a local significance.

For Local Soils it will best serve our purpose to use the ordinary names in every-day use; some examples showing their suitability have already been given. Such names have in many cases already been adopted by scientists.

Let us commence by establishing the characteristics of the following climatic soil forms:

Bleached Earths are free from iron and are hence soils which are deficient in colour-giving ingredients, apart from humus. In colour they are white or grey. To the Bleached Earths belong as climatic soil forms the Podsol Soils,* the

* Russian = Ash Soils, a name which well expresses the peculiar appearance of these soils, resembling wood ashes.

Northern Grey Forest Soils, all soils that contain appreciable quantities of soda and the Grey Steppe Soils.

Black Earths are soils rich in organic matter, whose humus is intimately mixed with the mineral portion of the soil, from which it cannot be separated by mechanical means. Hence mixtures of sand and vegetable mould do not belong to the Black Earths. The Black Earths are soils which have developed under the influence of arid climatic conditions. To the Black Earths belong the soils of Eastern Europe, for which it will be simplest to retain the Russian name for Black Earth—"Tschernosem." Other examples are the Prairie Soils of North America, the Regur or Black Cotton Soil of India, the soils of the coast-belt of Morocco, etc.

The Black Earths merge into the *Chestnut Brown Soils* of the warmer and more decidedly arid districts. The colour of these soils is due to organic matter which is distinguished by its bright brown colour from the humus found in most other districts. The Chestnut Brown Soils are to be regarded as a facies of the Steppe Black Earths formed under extremely arid conditions; their occurrence was first noticed in the neighbourhood of the Black Sea; their distribution in Central Asia has been described by Glinka[44] and they appear to be widely distributed in the West of North America.[45]

Brown Earths are soils whose colour-giving ingredient is a yellowish to reddish-brown hydroxide of iron. The Brown Earths are pre-eminently soils of humid districts; as a rule their humus content is not high, but is sufficient to give a characteristic tint to the colour of the soil. Brown Earths are widely distributed in Western and Central Europe, but their presence has also been demonstrated in the tropics.

Yellow Earths are soils which are characterised by their bright yellow colours. The colours are pure, since the soils are deficient in humus. The Yellow Earths have been described from the South of France, Morocco, etc. Up to the present they have not been investigated scientifically.

Red Earths are soils containing large quantities of ferric hydroxide. They are poor in humus and hence have brilliant

pure colours. The Red Earths are the principal soils of the tropics and sub-tropics.

Laterite as a Tropical Soil is connected with the Red Earths. The name has been chosen arbitrarily and is due to Buchanan, who applied it to an Indian Soil which, cut out and hardened in the sun, is used as building material by the native population (*later* = a brick).[46]

Other exceptionally coloured soils from the tropics have been described, e.g. from Brazil, but sufficient is not known about them to permit of their inclusion as a separate class in a classification.

Dry and Moist Zones. Arid and Humid Zones

The soils of the earth may be grouped into two great divisions which are defined according to the prevailing climatic conditions as Dry or Arid Soils and Moist or Humid Soils. Hilgard was the first to recognise this correlation and on this based a principal division into two large groups.[47]

Arid soils are soils in which the soluble products of weathering are preponderantly retained; drainage only takes place to a very limited extent.

The distribution of the soluble salts is chiefly controlled by the ascending currents of water. Arid Soils are rich in soluble ingredients or in those which are readily decomposed by acids; these frequently form crystalline deposits at definite depths in the form of sheets more or less parallel to the surface of the ground (soil horizons). Arid Soils are remarkably crumby, having but little coherence when dry (loose), so that they often exhibit the character of sands, even if the individual particles can be recognised as being compound (crumbs). Sand grains present in Arid Soils are surrounded by the finer particles as by a mantle.

Humid Soils are soils in which the soluble products of weathering are preponderantly removed by leaching, drainage water occurs annually and in considerable quantities. In Humid Soils the water current in the soil is predominantly downwards, with the result that the succession of strata

formed by weathering (strata A, B, and C) can be more or less distinctly recognised. Transportation within the soil, so far as it takes place, results in the removal of material from above downwards. The chief products of chemical weathering are hydrated silicates of aluminium (clays), and in the tropics, hydroxides of iron and aluminium. The soils, when heavy, are binding and tenacious (clayey), crumb formation extends to slighter depths than in Arid Soils and is restricted to that portion of the soil which is pervaded by animals and the roots of plants. Readily soluble ingredients are only present in trifling amounts.

The distinction between Arid and Humid Soils is clearly seen in all cases. Theoretically it must be assumed that there must be soils which stand exactly mid-way between Arid and Humid Soils; in practice such soils have not been found up to the present. Naturally there are transitional forms, but with the exception of a few cases amongst the Brown Earths the author has not become acquainted with any soils in which the classification presented any difficulties.

Seasonal Change of Climate. A considerable portion of the earth's surface has during the course of a year not a uniform but a changing climate, which is distinguished by the contrasts: —warm-cold and dry-moist. The soils of these countries are under the influence of a varying aerial climate and a varying soil climate. During periods when the temperature is below 0°C. soil transformations are at a standstill. The change from frost to thaw is of importance for the disintegration of rocks and the physical properties of soil. Once the soil is frozen, changes in temperature have little effect. Ice Soils, in the grip of "eternal" ground-ice, remain practically unchanged for centuries. This is also true of Air-dry Soils; but there are no districts in which the soil remains for a long time in the air-dry condition. There is, indeed, little probability of the prevalence of such conditions anywhere, since, even in decided deserts, deposits of dew are formed.

Soils in districts having a seasonal change in the climate but extremely low temperatures (frigid zones) display the

characteristics of Humid Soils*; it is only in temperate and warm climates that the effect of the seasons on soil formation is seen.

The Black Earths of the Steppes and Prairies are the best investigated soils which are typical of districts having a periodic climate with well defined climatic soil forms. The climate of these districts is usually described as "semi-arid." In the numerous investigations on these soils, which are fertile and therefore of great practical importance, attention has been directed almost solely to the influence of the aerial climate and to that of the vegetation. The soil climate and the influence of the soils on the vegetation have practically never been considered.

Kostytschew has shown conclusively that as a result of exclusively emphasising the aerial climate we are confronted with an enigma as regards the distribution of the Black Earths in Eastern Europe.[48]

The requirements for the formation of Tschernosem are: (i) high temperatures and a high saturation deficit during summer, with consequently high evaporation and dessication of the soil; (ii) lower temperatures and long lasting soil frost in winter. The soil activities are thus greatly reduced or brought to a standstill for long periods of time during the course of a year. In summer the climate is decidedly arid, in winter on the other hand distinctly humid. During the cold season water accumulates in the soil and this provides for the requirements of a luxuriant spring vegetation, which, however, ceases to grow after the exhaustion of the soil moisture between the end of May and the middle of June. In summer, drought, in winter, frost, retards the decay of the humus; the strong root systems of the Steppe grasses provide copious supplies of organic matter, and so a soil is formed having a high humus content.

During the intense evaporation in summer the ascending current of water in the soil is powerful, gypsum and calcium

* Polar Soils are apparently Arid Soils, cf. p. 93, also Wiegner G. (1921 *Boden und Bodenbildung*, p. 49; JENSEN, H. I. (1911), *Report on Antarctic Soils, Publ. of Brit. Antarctic Expedition*, 1907–9, *Geology*, vol. 2, p. 89.—(C. L. W.)

carbonate being deposited in distinct horizons. The result of the action of the soil-building forces is a soil of a distinctly arid type—the Tschernosem. If we reflect that from October till May, i.e. seven to eight months, humid conditions prevail in these districts, we see that the remaining four to five months are decisive for the soil properties.

"Semi-arid" as regards soil formation does not mean that the total precipitation lies somewhere in between those for humid and dry zones, but that the soil is under humid conditions for one part of the year and under arid for the other. The effects of both periods can be recognised from the properties and structure of the soil, but those of the dry period predominate to a considerable extent.

We are less acquainted with soil formations of semi-humid districts, i.e. districts having a periodic climate, and in the soils of which the properties of Humid Soils preponderate. In a restricted sense many Brown Earths might be classed here, but the climate during the warm season is not decidedly arid, so that these soils can best be grouped with the Humid Soils.

According to descriptions, the soils of the African Savannahs fall in this group. Under the prevailing high temperatures the processes of soil formation make rapid progress. Taking Vageler's investigations of the Mkatta Plateau as a basis,[49] there is a rainfall of 700 mm. (28 in.) in the course of two months which converts the soil of large expanses of the country into a thick broth. During the long dry season the soil is penetrated by deep cracks, and deposits of ferric hydroxide are plentiful. According to the published analyses these soils are decidedly humid in character. The short time of excessive rainfall is sufficient for the impression of a leached character upon the soil; the secondary deposition of iron is a phenomenon which is typical of Humid Soils.

Closely connected with the Semi-humid Soils we have the Reef Soils of calcareous mountains, which in spite of their limited distribution must nevertheless, be considered as climatic formations, even though their properties are modified by the parent rock. During summer these soils are exposed

to distinctly arid conditions, they become intensely dry and attain high soil temperatures. The jointing of the underlying limestone provides for the rapid removal of the seepage water, and at the same time prevents the ascent of water from lower layers during dry periods. By this means the soils acquire pre-eminently the character of Humid Soils, although they are exposed at times during the warm season to arid conditions. In this way a Black Earth, rich in humus, forms the soil on the Jura mountains in Southern Germany. This, although only occurring locally, is very characteristic.

The examples given show that the difference between Arid and Humid Soils is principally due to the movements of water in the soil. In actual fact there can hardly be soils in which water never, not even at times, moves upwards, and just as few soils in which water never percolates downwards. The properties of the soil will be decided by the prevailing current. Here, again, it is a question of a balance of forces, the displacement of which in one direction or another leads to the formation of one or another type of soil.

From this it will be seen that definite rainfalls or amounts of evaporation cannot be cited as being those which give rise to Humid or to Arid Soils. Temperature influences the rate of evaporation in a high degree; lower temperatures favour humid conditions, higher temperatures arid ones. In the arctic and boreal districts slight precipitations of 400 mm. or less are sufficient to impart a decidedly humid character to the soils; the slight evaporation is insufficient to use up even the trifling precipitation and water accumulates in the soil. In the tropics, on the other hand, a rainfall of from 1800 mm. to 2000 mm. and upwards (70 to 80 inches) is required to create humid conditions. In the Black Earth belt of Eastern Europe the rainfall is frequently not less than in many parts of Central Europe, but a high saturation deficit and high temperatures in summer result in such a great increase in the evaporation as to impart arid characteristics to the soils.

The difference between the two groups is also shown by their average chemical composition. The following figures summarise the results obtained by Hilgard in a comparison of

the hydrochloric acid soluble portions of a number of soils taken from the humid and arid regions of North America.[50]

	Humid Soils (696 analyses) Per cent.	Arid Soils (573 analyses) Per cent.
Insoluble residue	84·17	69·16
Soluble silica	4·04	6·71
Potash	0·21	0·65
Soda	0·14	0·36
Lime	0·11	1·25
Magnesia	0·26	0·96
Ferric oxide..	3·88	5·37
Alumina	3·66	6·31
Phosphoric acid	0·12	0·21
Humus	2·91	1·13
Nitrogen	0·34	0·13

The great extent to which Humid and Arid Soils differ as regards their content in substances soluble in hydrochloric acid is clearly seen; the difference between them would be even more prominent if a large number of soil profiles could be compared. This evidence is not only of great value for the theory of soil science, but it also shows how much greater is the store of plant nutrients which the soils of arid districts can place at the disposal of the vegetation than that which is available in the soils of humid districts. The former only need water for supreme fertility, the latter require manuring in addition.

Classification and Boundaries of the Climatic Soil Zones

Dokutschajew's investigations on the delimitation of the soils of Russia shewed that the separate formations extend in belts of varying width from South-West to North-East. The dependence of soil type upon climate was thus brought to light, and continued research gives it more and more prominence.[51]

Temperature, precipitation and evaporation are the three decisive factors concerned in the formation of soils. This is

distinctly seen, for instance, in a comparison of Europe and North America. Whereas in Europe on the whole, the aridity increases from West to East and from North to South, in the North American continent it increases from East to West. The broad soil belts in each continent are disposed in accordance with this disposition of climatic zones.

Further, smaller countries having independent climatic conditions, such as the Iberian peninsula, admit of climatic soil zones being clearly recognised.[52] The centre of the peninsula is occupied by Grey Steppe Soils, which are bounded on the West and North-East by Red Earths. In the South-East and South the nature of the soil approaches the conditions of Semi-Desert. The great orographic relief of Spain introduces irregularities without, however, causing any very great disturbance to a general view of the climatic soil zones.

In Europe on the Northern boundaries we have Arctic Soils (Flowing Earths, Tesselated Soils, Peat Hillocks), which are bounded on the South by intensely leached Bleached Earths, of which the most important representative is the Podsol.*

Further to the South the Brown Earths predominate in Western and Central Europe, while in the East the Northern Bleached Earths are bounded by the Tschernosem, the representative of the Black Earths in Eastern Europe. Saline Soils are found in the South-East; in the South occur Chestnut Brown Soils (closely related to the Tschernosem, but distinguished by the presence of bright brown humus).

South of the Alps in Italy we first find Brown Earths, and then Red Earths which are the dominant soils in the Southern Mediterranean districts, and extend far to the North where limestone is the underlying rock.

The Succession of Strata in Humid and Arid Soils.

The succession of strata in soils is known as the soil profile. A knowledge and investigation of the individual layers of a soil are invaluable as means of determining the conditions

* Russian = Ash Soils, after the bright grey colour of the Surface Soil, the appearance resembling that of wood ashes.

under which the soil has been formed, and of following the progress of changes that are actually taking place.

The evolution of a "Normal" Soil can be deduced from the processes of weathering.

Weathering starts at the surface of the soil, which is exposed to the greatest variations in temperature and to the continually renewed attacks of rain and snow-fall. The uppermost layer of the soil is therefore most completely weathered, i.e. comminuted by physical and decomposed by chemical actions. It is this layer which is usually permeated by the roots of plants and which is the home of the majority of soil organisms. As a rule the humus content of this surface soil is greater than that of lower layers.

Weathering is going on in all the strata of course, but the upper layer, which is attacked first, can reach an advanced stage of decomposition while the layer next below still contains an abundance of decomposable ingredients. By this means a soil may be divided into an upper, intensely weathered stratum and into a lower stratum in which weathering is still in full swing and which we can call the soil's horizon of weathering. The activity of the weathering processes decreases from above downwards, so that unaltered or only slightly altered rock may lie immediately beneath the soil.

For the "Normal" Soil we thus have a three-fold division which may be expressed by the terms: soil, subsoil, substratum or brash. Of late the expressions A, B, C-horizons are often used, following the example set by Russian investigators. If it is desired to make sub-divisions of these three layers, we may speak of A_1, A_2; B_1, B_2, B_3, etc.

The individual layers are differentiated both chemically and physically as follows:—

A. The Soil is more or less completely weathered. It is rich in ingredients which are readily soluble in water or in moderately strong acids; poor in still unweathered material; rich in organic matter and in fine earth.

B. The Subsoil contains moderate amounts of soluble and decomposable ingredients as well as moderate quantities of unweathered material. The organic matter content is lower

than that of the soil, the same applies to the finer mechanical fractions as contrasted with the coarser portion of the mineral ingredients of the soil.

C. The Substratum (brash, underground) consists of slightly decomposed rock which, in the case of massive rocks, is often shattered into a multitude of fragments. Chemically there is little change, its content of soluble and decomposable ingredients formed by weathering differing slightly only from that of the unaltered bed-rock. This may be the case even though the shattering is well advanced.

The division of soils into these three layers can be observed most clearly in soils having a high quartz content; they were probably first sharply differentiated by the author in the case of Sandy Soils.[53*]

In addition to uninterrupted weathering, soils frequently undergo changes which take place within the soil itself. Constituents may be dissolved and removed, or be added from without, with the result that though the profile corresponding to the process of weathering is certainly not destroyed, it becomes more or less indistinct. All changes in the soil are effected by water; but they are often caused or modified by plants and animals.

The most important of these changes are:—

1. *Mechanical Transport by Gravitational Water.* Finer grained particles are removed from higher to lower levels

* Russian investigators use these expressions in a rather different sense. "A" is the Eluvial horizon, from which substances are removed by leaching; "B" is the Illuvial horizon. This layer is enriched by additions from without. "C" denotes the parent rock. The Russian system of naming the different layers A, B, C, is useful and should be retained; on the other hand the conception of the Eluvial and Illuvial horizons can only be applied arbitrarily in many soils. The ideas have arisen from the investigation of Podsol Soils; here the upper layer is intensely leached, the middle layer is enriched by additions from above. In arid regions the upper layer is frequently enriched by additions from below; in a large number of other soils the middle layer does not receive any additions at all. On the other hand, if the threefold division of the soil is retained in the form proposed by the author, its close connection with the processes of soil formation are seen at once. Secondary changes may take place in close correspondence with the "Normal" Soil profile, as occurs in the formation of iron pan, but they may also be but slightly connected with the soil structure, or even have no connection at all, as for instance in the attainment of the crystallising concentration of ascending ground-water.

where they are deposited. In soils covered with vegetation, and containing sufficient quantities of electrolytes, such transport probably only occurs with the aid of plants and animals. The burrows of terrestrial animals, holes of earthworms, decaying roots, etc. all serve as channels for the washing down of finer particles from the upper layers of the soil. If the water circulating in the soil contains only small quantities of dissolved salts, so that the flocculating effect of the electrolytes is suppressed, transference readily takes place. It is probable that in the formation of the diluvial deposits of ice-borne material, leaching and transport of the finer material took place on an enormous scale.[54]

2. *Leaching of the soil* and the removal of the dissolved substances in the drainage water takes place in all moist districts. Where there is a seasonal change in the climate, as for instance in the Steppe Black Earths, leaching predominates during the cool and wet season. During the remainder of the year the moisture only penetrates to a certain depth in the soil before evaporation causes it again to rise to the upper layers of the soil.

3. *Water that is poor in salts* causes humus substances to swell with the formation of colloidal solutions, which render ferric hydroxide, aluminium hydroxide, and clay, mobile and so liable to removal. Substances from such colloidal solutions are deposited in those strata of the soil which contain large quantities of flocculating constituents, usually in the subsoil.

4. *Sodium carbonate* causes humus, ferric hydroxide, etc. to pass into colloidal solution. This effect is not shown by the bicarbonate. At greater depths of the soil where the carbon dioxide content is higher, the substances which were rendered mobile by the soda are precipitated as a result of the formation of bicarbonates.

5. *Soluble and decomposable substances* carried by the ascending ground-water from the lower levels towards the surface are deposited in the upper layers of the soil. Here they may form distinct horizons, of which those of calcium carbonate and of ferric hydroxide are the most important and most widely distributed.

Transportations and precipitations in soils are important in numerous processes of soil formation and characteristic of many soils. Each forms a possible basis for the classification and differentiation of varieties of soils.

Soil Zones and Soil Regions.

It is customary to speak of the distribution of the climatic factors in the direction of longitude and latitude as *zones*, their distribution according to elevation as *regions*.

The dependence of soil formation on climate is also seen in the distribution of soils according to the elevation at which they lie. It is the similarity, not the identity, of the conditions which brings about the close relationship between soils in zones and regions. In the frigid zones there is but little difference between the soils of different regions, but this difference becomes greater the nearer one approaches the equator. The most important climatic factor concerned is the angle at which the sun's rays strike the earth. This determines the amount of heat which reaches the soil and consequently the soil temperature and the evaporation of water from the soil.

An Arctic Soil is exposed to the feeble rays of the low-lying sun for long periods at a time. The soil of a high elevation in lower latitudes receives the radiation from a more nearly overhead sun in regular changes from day to night. Polar localities have long periods of constant conditions; high altitudes of the tropics have great changes at short intervals of time.

It is surprising how very little we know at present about the influence of elevation on soil formation. The action of frost is potent at high altitudes. Fragments of all sizes are split off the rock; boulders and gravel form a considerable proportion of the soils. As a rule, chemical weathering appears to make but slow progress. Humus and humus deposits are plentiful in soils of high altitudes; in many cases the bulk of the soil is composed of a mixture of fine gravel and mould, or the rocks are covered by layers of peat. On mountain slopes, landslides and creep are potent factors and prevent

the formation of distinct profiles. The influence of the parent rock becomes particularly prominent on calcareous formations.

As noted above, the conditions of formation and the properties of soils of climatic regions have received little consideration up to the present, still less have they been investigated. The climatic character of soil formation is particularly marked on plateaus and on broad mountain ridges, but can be recognised generally wherever the deposits are stationary. Mountains whose ranges extend at right angles to the direction of the prevailing wind frequently form the boundaries of different soil formations.

The distribution of the soils in the Caucasus gave Dokutschajew the first opportunity of establishing regional relationships.[55] In Central Europe peculiar soils, often over small areas, occur on medium and high mountains. The Molkenböden (probably = Buttery Clays) investigated by Vögel von Falckenstein remind one of Arctic Soils in many of their properties.[56] Podsol occurs on the Middle Bunter Sandstone of the Black Forest and of the Wasgen Forest as well as on the (Cretaceous) Quader Sandstone of Upper Silesia. In the Gotthard district are found peculiar Bleached Earths with iron pan; related formations occur on the moraines of the Tatra. The highest points of the Thuringian Forest, of the Hartz, the summit of the Riesengebirge, of the Bavarian Forest, etc. carry soils which are related to the Northern Bleached Earths, as well as locally occurring forms which are probably to be included in the Podsols.

The soils of mountain tops, often occurring in very small expanses, are economically of no great importance but they are adapted to display the fundamental climatic principles of soil formation, and to demonstrate the close relationship between soil zones and soil regions.*

The gradual change in the climate of Europe from West to East and from North to South leads us to expect transitions

* Although it is difficult to draw definite conclusions from the meagre data available, it would appear that in the British Isles an increase of 300 feet in the elevation is roughly equivalent to one degree of latitude, cf. WHITLEY, N. (1850), *"On the Climate of the British Islands in its Effect on Cultivation."* *J.R.A.S.E.*, **11**, 1.—(C. L. W.)

between the individual soils, and these are also frequently shown by outliers or inliers of one formation in a region strictly belonging to another. Smaller or larger patches of Tschernosem occur as far North as East Prussia and not quite so far North to the West of the Elbe (Magdeburg Border). Brown Earths frequently occur in districts characterised by Bleached Earths, etc.

The variations in the soils of large adjacent districts of different rock formation often disappear when the climatic conditions tend to cause the formation of a definite soil type. Under certain circumstances local influences become completely suppressed and a uniform soil covers even the most different rocks, as is found in the North with the Podsol, in the East with the Tschernosem, whose properties are only slightly different on Gneiss, Clay, Loess, Limestone, etc. This is in accordance with the rule that the more extreme the climate, the more generally will the climatic soil type predominate. On the other hand, in transitional regions, the local factors of soil formation become of greater significance.

It is surprising that even on the boundary lines, transitions between the individual soils are not found. The soil types are almost always sharply outlined against one another, often the boundaries are surprisingly well defined. The structure of a soil can vary within certain limits, the distinctive properties may be displayed more or less distinctly, but actual transitions seem to be rare. Even in the case of soils which in many respects are closely allied, as for instance Brown Earths and Black Earths, it is in vain that we seek border forms about which one could feel doubtful as to whether they belonged to one type or the other. This is not to say that it cannot often be difficult to classify soils correctly. As a contrary example one may instance the separation of the different forms of the Bleached Earths in the Glacial Drift areas of Northern Germany, which has hardly been attempted. Its completion will only be possible when we have learnt to point out the distinguishing properties correctly.

Chapter V

THE CLIMATIC SOIL ZONES

One's attention is first directed to the scantiness of the available material in an attempt to allocate the position of, and to delimit, the climatic soil zones. In addition to the intrinsic difficulties which interfere with the consideration of soils as deposits dependent on the climate, and this has only been recognised comparatively recently, there are other extrinsic difficulties. It is not easy on a journey, for instance, to get an insight into the soils of a district; this requires the examination of numerous exposures, often to a considerable depth, preliminary geological studies, and a correct appreciation of the local influences—all things which not only take time but also enthusiasm and the assistance of people having local knowledge. It will be readily understood that progress is but slow.

The Soils of Cold Zones

The soils of cold zones are Humid Soils. Low temperatures, slight evaporation and long continued frost cause even a precipitation of from 200 to 400 mm. to be sufficient to give the soils a humid character. The amount of chemical weathering which takes place is insignificant, the waters contain very small quantities of salts in solution; the soils are rarely stationary, Flowing Earths are of frequent occurrence.

The following forms have been distinguished[57]:—

Tesselated Soils (A. E. Nordenskjöld). The soils have a single grain structure. After the melting of the snow the soils are extremely wet, dry slowly and in this process crack into polygons of varying, but often considerable, diameter. The water in draining away follows the cracks, and removes the finer particles from them, so that sandy streaks separate the individual "tiles." In the broader polygons stones get carried laterally to the edges, so that rings of stones frequently

surround and separate soil surfaces made up of finer grained material. Soils with these characteristics are found in the extreme North.

Hillock Tundra. The treeless soils of the Northern boundaries of Europe are known as Tundra.* Considerable areas of the Tundra are covered with low earth hillocks, whose formation Ssuskatschew ascribes to the action of frost.[58] The lower layers of the soil contain ground ice; on the setting in of renewed frost the upper layer of the soil freezes; the soil is thus compressed between the two frozen layers and becomes arched up by the internal strains, and masses of earth are forced out through ruptures of the surface layer.†

Peat Formations are of general occurrence in the North. Only trifling amounts of organic matter are synthesised by plants in these districts; but the decay of the dead parts of plants takes place so slowly that the building up of plant substances, in itself of trifling dimensions, nevertheless exceeds the amount broken down. A special form of the Northern Peat Deposits is *Peat Hillock Tundra.* The growth of the peat-forming mosses is often tufted; they develop best when sheltered by shrubs such as Betula nana, Empetrum, etc., and in the lee of such shrubs, peat hillocks are formed. When the layer of peat attains a height of from 40 to 70 cms. its inner layers are insulated from rapid changes in temperature with the result that the cores of peat hillocks remain permanently frozen. The water supply is thus cut off from the surface mosses which die or are overgrown by lichens. Only on the slopes of the hillocks do they remain permanently capable of growth. The depressions between the hillocks serve as channels for the surface run-off of water. In this way there are formed series of peat hillocks and peat ridges divided by meandering channels which give the Peat Hillock Tundra its characteristic appearance[59]. In many cases it would appear that soil hillocks formed by the action of frost

* Tundra = treeless, as contrasted with Wooded Soils, hence Rock Tundra, Peat Tundra, etc.

† It is admissable that in mountains, e.g. the Bavarian Alps, low earth hillocks, which often occur in bulk, may have arisen through similar actions.

as in Hillock Tundra were originally the cause of the stimulated growth of peat-forming plants.

Frost-shattered Soils. Soils composed of fragments of all sizes frequently occur among the mountains of the North, whose origin must be ascribed to the shattering action of frost. The fine earth content is usually small. Frost-shattered soils are chiefly found on mountains and at high altitudes and are hence often spoken of as "Mountain Top Detritus."

*The Soils of Cold Regions.** Rock fragments of all sizes, without any appreciable coherence occur mostly as Shifting Soils on mountain slopes and declivities. The soils support but few plants and are consequently poor in humus, nevertheless, peat deposits having the character of forest peat are frequently found between the rock fragments.

Detrital Soils are typically developed on calcareous mountains and also descend with the progressive transport of the rock into warmer localities, where they frequently form talus screes and cones.

Mountain Meadow Soils (Bogoslowski).[60] The soils are a mixture of humus with a mineral framework which consists mainly of bleached rock splinters, but they also contain fine dusty material transported by the wind. This latter may even be present in preponderating quantities (Carpathians). On flat or slightly inclined situations a profile is developed; a loose pan being found under the shallow, bleached, Humus soil (Gotthard, Furka). On rocks deficient in calcium the Mountain Meadow Soils form a variety of the Bleached Earths, with which they are connected both as regards their origin and their properties.

Mountain Peat Soils. Peat deposits abound in high mountains where the conformation of the ground is suitable; they consist chiefly of species of Carex and leafy mosses; Sphagnums take little or no part in these formations.

The soils on calcareous rocks are of a different nature, and here again a distinction can be made between Meadow—and Peat—soils. The former are mostly a very dark, almost black mixture, having a neutral reaction, and rich in humus

* "Regions" as contrasted with "Zones," cf. p. 59.—(C. L. W.)

which is not dispersed by a dilute solution of ammonia, and in mineral ingredients. The Humus Soils of the limestone formations of the Alps have been designated *Alpine Humus* by Ebermayer.[61] They are beds of very black humus, loosely laid, neutral in reaction, usually composed of vegetable mould, more rarely of peat. If beds of Alpine Humus attain a great thickness their reaction becomes acid, and they resemble ordinary Peat Soils.

Arid Soils also may be met with in a cold climate. Such soils occur typically in the interior of Spitzbergen and in Greenland. It can be assumed that the soils of the Tablelands of Central Asia belong here.

Ice Soils. The varying depth at which permanent ground-ice is found exerts an influence on the nature of the soil. This is frequently observed in arctic districts; it can be taken as a general rule that running water facilitates the melting of the ice, layers of peat tend to preserve it. Outside the Arctic zone permanent ground-ice occurs in "mosses" (high moors) as in Finland; it is widely distributed in isolated portions of Siberia. The influence of the permanent ground-ice does not prevent the upper layers becoming warmed to a considerable extent, as shown by Prassolow[62]:—

Depth.	Under Forest 30th June, 1911.	Depth.	Under Cereals 21st July.
40 to 50 cms.	11·5°C.	20 cms.	14°C.
100 to 120 cms.	6·5°C.	40 to 50 cms.	12°C.
2 metres	0·5°C.	2 metres	0·5°C.

The profile of soils having ground-ice is sharply defined, a concentration of organic matter being found above the layer of ice.

The Soils of the Cool-Temperate Zones and Regions

As regards soil formation, the cool temperate zones fall into two large groups, which may be called the tracts of the Northern Bleached Earths and of the Brown Earths respectively. In the districts of the Bleached Earths Arid Soils are quite rare, this rarity being due to the same causes which usually

prevent the formation of arid types in the frigid zones, viz. low temperatures, long periods of frost and small evaporation. On the other hand, a phenomenon here comes into play which up to the present has scarcely been taken into consideration, namely that a great predominance of one climatic factor can diminish the significance of a second, so that within certain limits substitution can take place.

The soils of the West of Europe with high temperatures in winter, heavy rainfall and low evaporation are surprisingly like the soils of the Eastern districts with lower temperatures in winter, less evaporation and moderate temperatures in summer, so that if they are to be separated they can only be regarded as sub-divisions.

The influence of the parent rock exerts a profound influence through two factors: (*a*) the abundance or deficiency of calcium and (*b*) its effect on soil texture. It can be taken as a general rule that on calcareous rocks the Southern types extend furthest towards the North, and that on formations rich in quartz (sands) the Northern types extend furthest towards the South. The causes of this behaviour are very different.

The Northern Grey Earths acquire their distinctive properties from the action of humus sols, and on Calcareous Soils the calcium content prevents the formation of acid humus bodies, the products of decomposition being precipitated as the so-called "calcium humates." Acid Soils as a rule are rich in silica, especially in quartz; the slight water-holding capacity of Sandy Soils allows even moderate amounts of rain to penetrate deeply into the soil (a rainfall of 10 mm. saturates a Sandy Soil to a depth of 20 to 25 cms., a medium loam to a depth of only 4 to 5 cms.), and the large pores of the Sandy Soil enable the water to descend rapidly to the water-table. The amount of substances liberated by weathering is much less in neighbourhoods rich in quartz than in soils which are poor in quartz; the losses by leaching are therefore not only higher in themselves, but also in comparison with the total amount of soluble substances present. As an example of the persistence of the Northern Grey Earths towards the South

we have the heaths between Adour and Garonne, whose wind-blown sands have in part a Podsol profile.

The climatic conditions of the cool temperate zones cause the soils to be supplied with considerable quantities of water. The water-table is consequently high and usually close to the surface of the soil, which it not infrequently reaches. It follows that the soils frequently receive additions of dissolved decomposable ingredients from the ground-water, separations of hydroxides of iron being especially common.

In the cold districts of the cool temperate zones localities which formerly were dry often become converted into bogs and marshes, the process finally resulting in the production of "mosses" (Hochmoor). The process of bog formation is not yet known in all its details.[63] In most cases colonies of Sphagnums seem to be formed in woodland, and under their influence the soils become wet and the ground water rises in neighbouring areas. Sweden, Finland and particularly the North of Russia suffer extensively from the progressive conversion of their woodlands into morasses. A number of reasons support the theory that in the past the woodlands of Central Europe have suffered from drowning, though in isolated stretches, but that under the influence of civilised Man, drainage, etc., the action has been stopped. In high localities in the Mittelgebirge of Germany "mosses" are often found on former Forest Soils, as well as in the Hartz Mountains, Thuringian Forest, Black Forest, Bavarian Forest, etc. Numerous large "mosses" of Holland, North-West Germany and of the Eastern Baltic countries are closely related to drowned woodlands, unless it is possible to trace back their origin to the development of marshes which were present previously. "Mosses," on Humus Soils of an earlier date (peats), extend far towards the South, in Russia to Moscow and Kijew, in Central Europe as far as the Alps. The Southern limit of the formation of "mosses" on Mineral Soils is evident as a well defined boundary which passes through Holland and North-West Germany, cuts off a narrow strip from Mecklenburg and Pomerania, broadens greatly from the Province of Prussia onwards, and embraces a considerable portion of the North of

Russia. Scandinavia largely falls within the province of this regional "moss" formation. The Northern Grey Earths are divided into a number of sub-divisions, the limits of which are still imperfectly known. The distribution of typical Podsol roughly agrees with the regional distribution of "mosses."

The following sub-divisions can be made:—

1. *The Northern Type.* These soils, which contain excessive amounts of humus, are continually subjected to leaching by water which is poor in electrolytes with the result that all the mobile constituents of the fine earth are removed, and finally only a mixture of humus and sand (mostly quartz) is left. Pan deposits are scanty; for the most part all mobile portions are actually removed by transport. These soils are inserted, South of the forest limit, between the Arctic Soils and the true Podsol. They are widely distributed in the North of Scandinavia.

2. *Podsol.** Podsol is distinguished by the sharp threefold division of the soil profile.

The soil (A) is intensely weathered, its iron has been removed by the action of humus sols. The colour is a whitish grey, rarely with a pale reddish tint. The upper part of this stratum (A_1) as a rule contains more humus than the lower (A_2). The humus has the character of mould. The soil is separated from the subsoil by a sharp demarcation (without transitions).

The subsoil (B) is coloured brown to black by humus; on gentle ignition the soil first becomes darker in colour as a result of the charring of the organic constituents, and on prolonged heating there remains the mineral portion of the

* Russian investigators use the term Podsol in a broader sense than is employed here, and by this understand all soils possessing a distinctly and fully developed whitish horizon (A_2) (Glinka, Bodentypen, 69). If this layer is not well developed and the soil only contains whitish flecks and streaks, it is said to be "podsolic," if the layer A_2 is absent so that only faint indications of bleaching are seen, it is said to be "weakly podsolic." Expressions such as "podsolisation," "podsol formation," are used for the bleaching processes of the soil.

Only those forms are considered as Podsols by the author which have a thoroughly bleached upper soil, and a subsoil which is not only enriched by inorganic constituents, but whose weathering horizon contains large quantities of precipitated humus.

soil, stained red by ferric oxide. The humus is uniformly distributed throughout the soil, and coats the sand-grains present, often uniformly like a varnish. The humus thus has the character of a chemical precipitation; it is dispersed by dilute ammonia giving a brown to black coloured liquid. The reaction of the soil is distinctly acid, as in all the strata of the Podsols.

The upper layer of the subsoil is developed in the typical Podsol as a pan, which often extends deeper into the soil. The subsoil is distinguished from the over—and under—lying strata by the character of the humus and by having a higher content in acid-soluble inorganic constituents, particularly ferric oxide and alumina.

The pan is a layer of the soil cemented together by humus, and since the Podsols are preponderantly Sandy Soils, this is a "humus-sandstone." Soft, easily-friable pans may be termed "Earthy Pans" (Orterde). In soils which are deficient in quartz the pan frequently forms a continuous stratum which is also well defined on its under surface; in quartz sands it penetrates more deeply and often consolidates whole strata which are continuous with the normal substratum (C). Podsol is pre-eminently a soil type associated with sands; it seldom occurs on Loams, Loess and Clays, and then only in an exceptionally humid climate.

Podsol Soils and the formation of pan are the most thoroughly investigated soils and soil transformations; the fact that in spite of numerous researches there are still questions to be answered shows the great difficulties involved in the solution of soil problems. So far, the following appears to be established:—

Podsol and pan are closely connected with the formation of injurious forms of humus, especially those deposited in fissile layers on Mineral Soils (dry peat). The upper soil becomes considerably exhausted of acid-soluble minerals by leaching. Humus bodies having an acid reaction are present in the soil and these form colloidal solutions (sols) with water. In the subsoil, the zone rich in easily weathered silicates, reactive compounds are continually being liberated, and the humus substances carried down by the seepage water are

precipitated; at the same time ferric hydroxide and aluminium hydroxide are set free. These envelop and cement together the mineral particles of the subsoil.

The Podsol Soils are distinguished by the intensely weathered upper layer, exhausted by leaching, the enrichment of the subsoil by substances carried down from above, and the nature of the humus substances. Occasionally peat in course of deposition can replace the stratum A and precipitations of humus then take place directly on the surface of the mineral soil. But the formation of Podsol always requires an upper soil stratum which gives rise to the soluble and mobile ingredients which are carried down to the level of enrichment B.

Podsol is the dominant soil of cool districts with low evaporation and a rainfall which is sufficient for the leaching of the soil. Podsol formations and regional formations of "Mosses" occurring on Mineral Soil have roughly the same limits of distribution. Both are common in Northern and North-Western Europe, and on sands encroach upon warmer districts. Podsol frequently occurs at high altitudes in the Mittelgebirge of Europe. The dominant plant formation of Podsol Soils is the Northern Coniferous Forest.

3. *Bleached Earth Forest Soils* (Grey Forest Soils of the Russian investigators).

In the Southern portions of the districts of the Northern Bleached Earths soils are found which are subject to the same weathering as leads to the formation of typical Podsols but in a lesser degree, so that the Grey Forest Soils have rightly been detached as independent forms (Dokutschajew (1883), well described by Müller (1883)[64]).

The soil profile is very characteristically developed in sands. The soil (A) is crumby as contrasted with the structure of Podsol; according to the humus content the colour is light or dark grey. Soil (A) and subsoil (B) are not sharply differentiated but show a gradual transition in which the boundary can only be established by careful examination. The soil fauna, in which the larger kinds of worms are almost entirely wanting in Podsol Soils, is apparently numerous and normal; bacteria are present in abundance. The soil (A) is free from

iron, but is not deficient in acid-soluble ingredients. The soils have a weakly acid reaction; treated with dilute ammonia they give yellowish-brown to brown solutions, which as a rule become darker after prolonged action.

The subsoil (B) is crumby, and coloured reddish-brown by humus. Downwards the horizon gradually merges into the light coloured substratum (C). A network of more or less distinct dark streaks is frequently interwoven with the soil, which it divides into irregular polyhedra, a soil structure termed "pea" or "nut-structure" by Russian investigators.

The Forest Bleached Earths are one of the most unstable soils known, and under unfavourable conditions readily pass into typical Podsols. Excellent examples of this are afforded by the heaths of Western Europe. So long as traces of woodland are present, even if only in the form of bushes, the soils retain the characters of Forest Bleached Earths. Under heather on the contrary, they are converted into typical Podsol, often with the formation of pan.

The conversion of Tschernosem into Forest Bleached Earths has aroused special interest. The Black Earths of Eastern Europe are surrounded towards the North and West by a circle of "Grey Forest Soils," which are frequently derived from the transformation of Black Earths and are designated "Degraded Tschernosem" by the Russian investigators. Numerous reasons lead us to believe that, after the Glacial Period, the Steppes had a greater expanse and were only gradually colonised by woodland. Under forest an alteration in the soil climate took place which was sufficient to bring about different conditions for the formation of soils from those prevailing under Steppe.

Experiments have shown that on the border line between Forest and Steppe, the Steppe can be rapidly changed by afforestation. The same changes have taken place in the case of the retreat of the Forest in favour of Steppe. Evidence of the occurrence of former Steppe Soils is afforded by the burrows of Steppe animals inhabiting the soil; the burrows, which have become buried and filled up with Black Earth, remain distinguishable for a long time. Further signs are the

marked nut-like structure of the soil and, in the East, the occurrence of a reddish-brown layer in lower levels of the soil.

The distinctive features of Forest Soils as compared with Steppe Soils are: lower temperatures during the warm season and larger quantities of moisture in the upper layers of the soil. An ample water supply provides for the requirements of a large bacterial population and so accelerates the decay of the humus. The loss of the humus must reduce the volume of the soil and is probably the reason why the seepage water follows definite channels. Perhaps the variations in the completeness of the extraction of water by the plant roots in the separate parts of the soil can also cause changes in the volume of the soil and so lead to the formation of the nut structure. In heavy soils the individual "nuts" are surrounded by a thin layer of Bleached Soil so that when dry they appear dusty.

The Forest Bleached Earths are for the most part covered by mixed deciduous broad-leaved forest. On Sandy Soils pines are associated with the broad-leaved trees. According to the author's experience the oak is a species under which the "nut-horizon" developes readily. The plant formation of the mixed, deciduous broad-leaved trees is much less restricted to one type of soil than that of the Northern Conifers or of the Steppe plants.

The Forest Bleached Earths are found in the Northern portions of Central Europe and in the frontier districts between Steppe and Forest in the East. They penetrate further to the South on sands and occur, for instance, among those soils of South Germany which were originally derived from the weathering of exposed sandstones.

Local Soils of the Northern Bleached Earths

The Northern Bleached Earths are a well defined formation whose dependence on the climate is shown by the fact that all soils within the obvious limits of the Bleached Earths are uniformly converted into Bleached Earths whatever their derivation. At the same time these zones are also districts where the water-table is high and where the decay of the dead

plant residues takes place slowly. The Local Soils are therefore, in the main, deposits which are under the influence of the ground-water, or are formed under water, or owe their origin to accumulations of humus. These Local Soils may be divided into (i) Sub-aqueous Soils, including certain Peat Soils; (ii) Humus Soils, and (iii) soils which are under the influence of the ground-water (Muck Soils).

Soils of these groups can naturally be formed in every climate, but Humus Soils attain their greatest dimensions and are more widely distributed in a cool climate with small evaporation than in other climates. The Sub-aqueous Soils are also perhaps best investigated here, and the same applies to the still but slightly investigated Muck Soils. The proportion of the ground which is under water varies greatly in different countries; according to Frosterus at least one-third of the area of Finland is submerged.[65]

1. *Sub-aqueous Soils.*

These are soils which are either formed under water or are regularly covered by water at short recurring intervals (tides). The division between rock deposits which are regarded as geological formations and soils is an elusive one; it will be best if we allot to soils those formations which are commonly converted into dry land, and allocate to Geology those which can only become land by a great change of elevation. In genetic investigations no distinction will be made; for the purposes of Soil Science it is necessary to include some of these formations with soils, such as, for example, the deposits of peat formed under water, pond-mud, mud deposits, etc.

Sub-aqueous Soils are formed under water and consist of deposits, and their transformations, which arise from the sedimentation of the remains of the flora and fauna, excrements of animals, etc., mixed in varying proportions with material supplied from external sources by flowing water or by the wind.

Mud or Sapropel. The deposits formed under fresh or

brackish water from the residues of swimming organisms (Plankton) mixed with mineral particles (clay, sand), comminuted peat supplied by water (clay mud, sandy mud, liver-coloured mud), or pollen (Fimmenite) carried by the wind are, in accordance with the rights of priority, most correctly known as Muds (Weber), (Slimes, Sapropel according to Potonié). These deposits are intensively worked by the organisms living in muds, especially worms, and improved by chemical precipitations from the water (chalk, ferric oxide, humus substances). If one ingredient preponderates, differences in facies are brought about, examples of which are the layers of calcium carbonate which often attain a considerable thickness (Meadow Chalk, German Alm).

There is still but little known about the metamorphoses of mud deposits, it is only quite recently that it has been shown that a Humus Soil under water containing large quantities of calcium carbonate (probably with the assistance of the micro-organisms present) can in a short time be converted into a calcareous mass (Fischer).[66] On the other hand, it must be borne in mind that a calcareous mass exercises a flocculating and precipitating action on humus bodies present in colloidal solution (humus sols) and on compounds of iron which may be present in the water. On the whole an extensive interchange takes place between the mud and the substances dissolved in the water which permeates it.

2. *Humus Soils*. Peat, which consists of compact coherent masses of plant residues, usually forms the basis for the formation of unequivocal Humus Soils.

Peat Soils vary in their properties according to the plants from which they have been formed. They may be divided into three large groups, according as they have arisen mainly from the vegetation by means of which expanses of water have been converted into land—Fen Peat; from the remains of trees—Carr or Forest Peat; or from a moss-flora—Moors, or especially Sphagnums—"mosses."[67] The special term "moss" is often given to Humus Soils mainly derived from the decomposition of bog-mosses (Sphagnum).

The three groups of peat-forming plants constitute

independent plant communities, but they are much more closely inter-related by transitions than is usually assumed.[68]

Peat formation is dependent on the climate but is largely influenced by the properties and the demands of the peat-forming plants.

Fen (Lowland Peat) is formed by the transformation of stagnant or slowly flowing waters into land, particularly by Cyperaceae (Reeds and Sedges) and by leafy mosses (Hypnum). Amongst trees, the Alder under certain conditions can play a considerable part in peat formation. The greater bulk of Fen consists of the remains of roots and rhizomes growing under water and of club mosses.

The dominant plant species vary in different climates, they also depend to a large extent on the water's content of nutrients so that a distinction can be made between "hard" and "soft"-water formations.

When the processes of conversion of an expanse of water into land has reached such a stage that the currents are retarded and that the convection currents in particular (in a vertical direction) no longer bring about significant movements of water from one level to another, a different phenomenon leads to the replacement of the "hard"-water plants, which mostly predominated at the beginning, by less exacting species. The less dense water supplied by rain, snow and by melting ice collects on the denser water richer in salts, in somewhat the same way that a layer of fresh water floats on salt-water in sand dunes on the sea coast. The more exacting "hard"-water plants are gradually supplanted by species belonging to the association of "soft"-water plants. In this way peat deposits frequently develop a saucer-shaped structure, since from the bank to the centre of the original surface and from the bottom to the surface less exigent species follow one another in succession.

After the water basin has been filled with peat, the whole bulk of the peat behaves rather like a layer of water without any convection currents, consisting as it does of from 70 to 90 per cent. of water by weight. The temperature of the Peat Soil corresponds to its high water content; the upper

layers are cooler during periods of high temperatures, but warmer than Mineral Soils when the temperature is falling. Hence Peat Soils have lower Spring and higher Autumn temperature than Mineral Soils. Neither the daily nor the annual variations in temperature penetrate to any great depth in the soil, and there is a considerable lag in the maximum and minimum temperatures of the lower levels, so that even at moderate depths the highest temperatures can occur in the winter and the lowest in summer. The mists, which in autumn and at night often lie on the surfaces of bogs, are therefore a result, not of a lower but, of a higher temperature of the Bog Soil.

The temperature of the soil probably plays a leading part in the formation of peat; on the whole the temperature of the separate layers of the soil will be considerably lower than they are at the same distance from the surface in Mineral Soils. It is much more probable that it is the average temperature, especially the lower temperature of spring and summer, rather than the lack of oxygen, which retards the decay of the plant remains and so is responsible for the accumulation of peat.*

Carr or Wood Peat. Wood peats differ fundamentally from those formed by the conversion of expanses of water into land both as regards the conditions of life of the peat-forming plants, their mode of formation and their properties, and must thus be considered as a separate type of peat formation.

Wood peat is formed from the remains of trees together with the lower vegetative covering of the soil (herbs, mosses, etc.). The remains of the roots of all these plants frequently contribute to its formation. The process of the formation of wood peat can be followed in all its stages. The first indications of the development of peat are given by the forest-litter becoming solid and compact; this marks the commencement of the deposition of the "sour" or "acid" humus of the forester, which with a further increase in thickness is converted into coherent fissile masses—the forester's "dry peat." Such an accumulation finally leads to the laying down of thicker beds of wood peat.

The accumulation of large beds of wood peat is an event which is brought about by the climate; the distribution of

* See footnote, p. 24.

wood peat on Mineral Soils and its preservation as a soil formation roughly coincides with the distribution of regional "mosses" (Hochmoor); in warmer districts wood peat is often found in beds of a considerable thickness on Humus Soils which have been formed previously. The influence of the climate on the formation of wood peat is illustrated by the fact that trees, such as the Beech and Pine, which in favourable localities do not form dry peat, in a different climate become powerful producers of peat.

"*Mosses*" (High Moor, Upland Peat). Of all the plant communities with which we are acquainted, "mosses" form one of the most characteristic formations and, apart from the climate, one most independent of external influences. Only a small number of species are concerned, amongst which the bog-mosses (Sphagnums) predominate. In the main, the distribution of the Sphagnums roughly coincides with that of the Northern Coniferous Forest, with the exception that on former Humus Soils they extend considerably further to the South. In the arctic zone, the Sphagnums are not dominant, their place being taken by species of Dicranum which are similar in structure and in vital requirements.

The flora of "mosses" consists of the least exacting plants that we know; the annual increments of organic matter are small, the mineral requirements inappreciable, so that they can be for the most part supplied by the additions of wind-blown dust; the rain supplies nitrogen, and ammonia is also probably absorbed from the atmosphere by the vegetable substances having an acid reaction. The anatomical structure of moss enables it to accumulate water; the unlimited apical growth of these mosses, the slow continuous decay of the dead portions, their tufted growth in all dry places not only enable peat mosses to survive, but bring about the accumulation of water and the water-logging of the soil.

The peat formations of great economic importance known as "Transition Moors" (Intermediate Moors, Mixed Moors) are probably best regarded as special forms of the moor. The name is given usually to Fens in which the hard-water plants are in course of being suppressed by species typical of

fresh-water, without however losing the character of Fen. The invasion of Fen or Carr by true "moss" Sphagnums is not an intermediate stage, but the commencement of the formation of a "moss" on previously existing Humus Soils.

Transformations of Peat Soils. Vegetable Moulds.

Peat Destroyers. If expanses of water have been converted into land by the formation of peat to approximately the height of the former water level, and the conditions for the formation of peat are thereby disturbed, as frequently occurs with Carr in particular, plants become established which destroy the coherence of the compact peat and change it into fine earthy material (mould):—*Vegetable Mould Soils.* (To the Mould Soils belong the Moorland Soils and Moor Marls of the German Geological Survey.)

It is especially the grasses which bring about the conversion of peat into vegetable mould by means of their well developed root system which penetrates the peat peculiarly intimately, thus breaking it up very efficiently. In Germany the most important destroyers of peat are Molinea coerulea L. (purple moor-grass) and Aira flexuosa L. (heath grass). A few years are sufficient to convert less resistant layers of peat into mould. The animal kingdom also takes part in this change, earthworms and moles in particular being important auxiliaries. In the reclamation of moors Man promotes the conversion of the peat by mechanical cultivation, his activities resulting in its conversion into mould within a few years.

Successions of Peats. Fully developed beds of peat form favourable habitats for the growth of other peat-building plant formations which flourish in moist Humus Soils. It can be taken as a general rule that for the most part peat-destroying grasses occur on Fen and these are soon overgrown and suppressed by trees (Birch, Alder, Pine). Wood peat develops under the trees and this in turn provides favourable conditions for the "moss" vegetation which gradually kills the trees and becomes dominant.

In many cases, particularly in the zone of the regional formation of "mosses," wood peat develops first and is later

invaded by peat mosses during water-logging of the soil; the woodland is then followed by "moss." If for any reason the water supplies of the "moss" are diminished, it once more becomes a suitable habitat for trees. We can thus have woodland on "moss" with a Carr Soil.

Another form of the growth of "mosses" is caused by the lateral expansion of the "moss." The apical growth of mosses continually increases the thickness of the layer of moss-peat, so that the "moss" rises like a flat cake well above the original height of the country and allows water to drain away in all directions. The neighbouring areas become water-logged, any forest that is present is killed, and the "moss" slowly but irresistibly spreads outwards from its edges. The retreat of the Northern Forest limit is due to the conquest of the forest by the "moss."

The Weathering of Peat Soils.

Isolated peat deposits, like all other soils, are subject to progressive weathering and transformations. The organised structure of the peat is more or less destroyed, the whole mass becomes more uniform and more compact. "Mosses" in particular show the difference between older and younger peats. Most of the "mosses" of Europe show an organisation into lower (older) moss-peat and upper (younger) moss-peat, which are separated by an intermediate layer. This is composed of plants which correspond with the vegetation of the present time, and has often given rise to the assumption that changes in climate have taken place within historical time.

The most important modification of peat is connected with its leaching by seepage water. Peats, especially the loosely packed fibrous varieties, are tolerably permeable to water; a slow stream of water flows from the higher parts of the moor towards the lower-lying portions. The peat is subjected therefore to continuous leaching, and in districts of a heavy rainfall may lose quite considerable portions of its minerals.*

* An excellent example of this effect is afforded if the moors of the Bavarian border of the Alps with a rainfall of 1200 to 1500 mm. are compared with those of the lowlands of the Danube with a rainfall of 600 to 800 mm.

The amount of evaporation from the surface of the moor is considerable, and this is probably increased if more exacting species replace peat-forming ones. By this evaporation, the water content of the upper layer is diminished and conditions are created that bring about the separation of unstable compounds. Deposits of ferric hydroxide are not uncommon; these are particularly abundant when iron sulphide, never entirely absent from peats poor in calcium, is present in large quantities. Depositions of calcium carbonate are common in Fen. These are either distributed throughout the whole mass (moor marl, peat marl) or deposited in smaller or larger concretions. The form of the occurrence suggests that it is mainly a question of deposits formed by the ascending ground-water, in which case the deposit may originate from the shells of mussels and snails or from supplies of water rich in calcium carbonate.

2. *Soils under the Influence of the Ground-Water.*

In the districts of the Bleached Earths many soils are under the influence of the ground-water. Ferrous carbonate is often present in solution in the ground-water, and on the whole is found in larger quantities according as the conditions favour the deposition of humus and the formation of colloidal solutions. We know from experience that ferric ions are easily reduced by humus bodies, on the other hand, hydrated ferric hydroxide is not attacked directly. The general occurrence of iron in solution in the drainage water of the lower levels of the soil, however, proves that changes do take place which lead to the formation of soluble compounds of iron. In the absence of oxygen, ferrous compounds are stable in solution, on the access of oxygen they are oxidised and converted into ferric hydroxide. This requirement is fulfilled wherever the soil is well aerated. The deposition of ferric hydroxide is promoted by all influences favouring the ascent of the ground-water, including the action of the roots of plants, of trees in particular, in imbibing water.

Ferric hydroxide is deposited in different forms. At one time, it will be uniformly mixed with the soil in a fine state of

division, at another ferruginous streaks, sheets or veins may extend from the average level of the water-table to the upper layers of the soil. In many cases, the roots are covered with a coat of iron rust which may often attain a considerable thickness. The precipitated ferric hydroxide frequently cements the soil particles together, especially in Sandy Soils, forming Ferruginous Sands and Sandstones, or separates out in concretions or in coherent banks.

Soils which are under the influence of ground-waters containing iron acquire an entirely different appearance and different properties as a result of the secondary deposition of ferric hydroxide. Wysotsky designated deposits of this kind "Glei" deposits and the soils as *Glei Soils* after a Russian local name.[69] This term has since been applied to all deposits formed by the rise of the ground-water,[70] but it seems more expedient to restrict it to the soils of moist temperate zones.

The deposits in the Glei soils consist mostly of ferric hydroxide, occasionally of manganese dioxide and rarely of calcium carbonate. The predominance of compounds of iron differentiates the deposits formed by the rise of the ground-water in moist districts from those of arid districts in which calcium carbonate preponderates.

Glei Soils are not restricted to level situations but are also found on slopes carrying ground-water, and here often attain a considerable thickness. The deposits from springs are closely related to the Glei deposits as they arise from similar chemical reactions. They are distinguished by the frequent occurrence of calcium carbonate.

Meadow Soils. Soils with a flat water-table which are quite saturated by the ground-water at least during the cold season have a special character. The dominant plant formations are chiefly moisture-loving grasses and Cyperaceae. Soils of this kind are known as Meadow Soils; they differ in structure according as they occur on sands or clays.

The *Sandy Meadow Soils* (this includes the Alluvial Sands of the German Geological Survey) are rich in humus in their upper layers; the humus is of the vegetable mould type. The subsoil is poor in humus and usually has a bluish grey colour.

This colour is regarded as a sign of reducing processes in the soil, and is also assumed to be connected with the separation of small quantities of iron sulphide, as these soils lose their colour on coming in contact with the air.

Limonite concretions are often found in the substratum of Meadow Soils. These are not removed when the soil is inundated. For the most part they consist of irregularly shaped grains with a rough surface. The occurrence of iron concretions is a useful indication that the aeration of the soil is insufficient throughout the year or at least for the greater part of the year.

Meadow Soils on Clay. The occurrence of heavy forms of Meadow Soils is universal throughout the districts of the Bleached Earths, the character of the soil only changing slightly Underneath a soil which is more or less rich in humus there is found a fissured subsoil which readily breaks up into thin sheets and scales, particularly when thoroughly dry. The surfaces of the individual fragments are coated with a thin dark coloured deposit of iron compounds. The structure of the soil is due to the difference in volume of the soil when in a wet and in a dry condition. During winter the soils contain large quantities of water and dry out during the vegetative period with the formation of cracks. The ascending ground-water predominantly follows the channels provided by the cracks and here deposits its iron compounds. The structure of Meadow Soils and the deposits of iron are easily recognised and are distinctive of these soils.

Meadow Soils occur in depressions in flat or gently sloping country, also frequently as marginal formations of rivers and lakes. They are often found in conjunction with Fens, which are frequently surrounded by a broader or narrower belt of Meadow Soils.

Limonite Soils. These are continuous with the Glei Soils and are to be regarded as their most fully developed forms. Limonite occurs in concretions or in solid banks. The profile of Limonite Soils depends on the depth to which the soil is aerated. The deposition of ferric hydroxide starts at the limit of aeration of the soil, i.e. where oxygen comes into

contact with the ground-water or with ascending currents of water. The ferric hydroxide which is deposited consolidates the soil and reduces the aeration. In this way the limit of aeration rises to higher levels and may even reach the surface of the soil and the limonite then forms solid banks. Ferrous carbonate has been found in the lower layers of beds of limonite. Hence there can be no doubt that the deposition of dissolved compounds of iron can result from purely chemical processes. In nature this is often brought about by the activities of micro-organisms. Certain groups of bacteria appear to be able to utilise the energy set free by the conversion of ferrous carbonate into ferric compounds for their vital processes and to bring about or at all events promote the formation of iron deposits.

The author has really followed the example of his Russian predecessors in the treatment of the Glei formations, which deserve careful consideration on account of their wide distribution and the great changes which they produce in soils. It is, however, uncertain whether it is justifiable to separate Glei Soils as special types. Glei formations can occur and are actually found wherever the soil is under the influence of a high water-table; regarded as an independent soil type the Glei Soils are exclusively characterised by secondary alterations which neither have anything to do with the original processes, nor rest on a climatic basis. It will, therefore, perhaps be advisable to speak rather of soils with a Glei structure than of Glei Soils, and to classify them as local varieties.

Warp Soils (or Alluvial Soils).* These soils are formed by the deposits of rivers; so long as they lie within the reach of regularly recurring floods they continually receive material transported from outside. On this account they are greatly dependent on the nature and composition of the districts drained by the rivers. For a shorter or longer portion of the year the Warp Soils are not flooded and during this period are

* Warp is the term applied to an artificial soil obtained in this way in Lincolnshire. The scope of the word is extended here, but seems preferable to Alluvial as it emphasises the continual additions received by the soil.—(C. L. W.)

subject to the weathering prevailing in the locality; they are therefore to be regarded as more or less Local Soils of the separate soil zones, and to be grouped with the respective soil zones when these are more thoroughly investigated. The Warp Soils include the alluvial deposits of the lowlands which in the case of the large rivers often attain enormous dimensions (Ganges, Nile, Mississipi, etc.).

The Warp Soils of the German rivers abound in Glei structures in the lowlands. They consist of mixed deposits of silt and sand, which under the influence of annual additions and of living organisms have a favourable soil structure and are usually extremely fertile. In the outskirts of the Alps the rivers mostly carry calcareous sand, the grains of which become cemented together after deposition. These give rise to Calcareous Soils that are rich in humus, over loosely consolidated calcareous sands.

Marsh Soils. (Knick-Crack). On flat sea coasts with regular tides but without strong currents, mixtures of organic and inorganic particles are deposited and retained by the plants that are present. These muddy deposits are converted into land when they rise bit by bit above the regular flood-level. On the German shores of the North Sea the soils formed in this way are known as Marshes, Marsh Soils or as Klei Soils.* Marsh Soils are widely distributed on many coasts (e.g. mangrove swamps) but up to the present have not been carefully investigated, with the exception of the deposits of the shores of the North Sea.

These maritime muds (Schlick) are to be regarded as the salt water forms of Mud deposits in whose formation and consolidation organisms play an essential part.[71] The Klei is a very fertile soil containing large quantities of both humus and clay. Under the climatic conditions prevailing on the shores of the North Sea it loses calcium carbonate, its structure deteriorates and it is subject to extensive Glei formations which cause the roots of plants to become covered with deposits of iron. These deteriorated Klei Soils are known as Knick.[72]

* Klei from kleiben = kleben bleiben = to cling, a soil that clings to one's feet. (Possibly the origin of our "clay."—C. L. W.)

Saline Soils of the Bleached Earths.[73] Soils are found in the districts of the Bleached Earths which have a varying content of salts, usually in isolated patches but also in some cases extending over wide areas. The analyses show varying amounts of gypsum, sulphates of iron and magnesium, and of alum. The occurrence of soluble salts in decidedly moist districts can only be explained through the salts being continually formed afresh in the soil. This requirement is fulfilled on impermeable soils containing iron sulphide, which on oxidation yields sulphuric acid; the sulphuric acid attacking the mineral portion of the soil and forming soluble salts. Many peats and certain muds contain iron sulphide, as a rule in very small quantities, but occasionally in considerable amounts.

Of the forms found in Germany we may mention:—Darg, a sedge peat of North-West Germany containing iron bisulphide, and Maibolt (Poison Soil, Powder Soil) containing iron sulphide and free sulphur, a type of mud formed especially in brackish water. Many clays also contain iron sulphide and yield salts as above on weathering.[74]

In the Northern districts of the Bleached Earths there are other soils which have an acid reaction and contain hydrolysable salts such as ferrous sulphate and alum. Finland and Eastern Siberia have large areas covered by Saline Soils of this type.

Flowing Earths of the Bleached Earths. Amongst the soils which have arisen from the Northern glacial deposits are found silty and fine-grained sandy soils which are rarely stationary, and which should be classed as Flowing Earths. They are compact soils of single grain structure which when saturated with water begin to flow, and which ooze or gush out of the sides of ditches and other cuttings as a thick earthy broth. The Floating Sands of Hanover (Sinking Soils of Westphalia) are silty quick-sands; soils of the same nature are also found in Scandinavia.

The Brown Earths

The Brown Earths develop in temperate climates with a moderate evaporation and medium temperatures. Similar soils are formed in the tropics under decidedly humid

conditions without seasonal variations. The Brown Earths are the dominant soils in Western and Central Europe, but extend far to the South, being met with, for instance, in Italy. They are bounded on the North by Grey Earths, on the East by Black Earths and on the South by Yellow and Red Earths.

The climate of the districts of the Brown Earths varies according to the season. The rainfall is not sufficient during the warm season to form seepage water in soils which are covered with vegetation. In warm and dry years slightly arid conditions prevail, so that the effects of the ascent of the ground-water are seen. This is mainly evidenced by the soil water being enriched in calcium carbonate, though deposits of calcium carbonate in appreciable quantities are rare or are only found in soils having an abundant water-supply, as in the Loess. Leaching preponderates in most of the Brown Earths; the soluble salts and the earthy carbonates are washed out, while phosphates and the sesqui-oxides (Fe_2O_3, Al_2O_3) are retained in the soil.

In spite of the considerable quantities of organic matter formed by the plants, the humus content of the soils is low to medium, being rarely high on account of the somewhat rapid decay of the humus substances. The amount of humus present is sufficient however to impart an artificial dirty tint to the soil as contrasted with the pure colours of Yellow and Red Earths with their low humus content. The soils vary in colour from yellowish-brown to reddish-brown, colours dependent upon the variation in the content of yellowish-brown to brown hydroxides of iron; lighter yellow-brown or darker brownish-red colours are not rare. Red colours occur when the parent rock contains free oxides of iron.

In the Brown Earths humus principally occurs in the form of an intimate mixture of the humus substances with the mineral portion of the soil, which can only be separated by chemical methods. The soil has normally a neutral or slightly alkaline reaction; hence readily dispersed humus bodies are not found. Treated with a dilute solution of ammonia, they give yellowish to yellowish-brown liquids (usually cloudy owing to the presence of clay particles) which do not darken

or only assume a darker colour after prolonged contact between the soil and the solution.

In addition to the form of the ferric hydroxide, the Brown Earths are characterised by their content of hydrated alumino-silicates—the clay substances. Even small quantities of clay are sufficient to give the soils coherence; hence the Brown Earths are "binding" or "tenacious" soils. As a rule crumb formation does not take place to any great extent, and in agricultural practice regular cultivation and the addition of organic manures are required to maintain a good tilth.

The Brown Earths develop under the influence of a temperate climate which fluctuates greatly; some years are wet and others dry so that the leaching of the soil is very much greater at some times, very much less at others. It so happens that the districts covered by the Brown Earths have a well marked physiographic relief, the land being intersected by numerous mountains, and under these conditions the local factors become very significant. In no other soil formation does the parent rock exercise such a large influence as in the Brown Earths. This explains why Fallou, to whom we are indebted for the first attempt to classify soils scientifically, really based his classification on the parent rock. Fallou conducted his researches for the most part in Central Germany.

On account of the continental situation the climatic differences are shown more sharply in Eastern Europe than in temperate Central and Western Europe. In the East, Bleached Earths and Black Earths often border one another directly, the transitional form of the Brown Earths being either absent or apparently less typically developed.*

* Glinka (Typen der Bodenbildung (1914) and several papers in Potschwowedenie (Pedology)) expresses the opinion that the Brown Earths described by the author correspond to the weathering layer "B" of the Bleached Earths and are not independent soil types. The "B" stratum of the Bleached Earths is a horizon of enrichment and receives additions of the products of weathering and of substances transported as colloids from the overlying layers. The "B" stratum of the Bleached Earths thus postulates the presence of an upper leached layer or at least of a layer of humus. It is incomprehensible how soils having the properties of the "B" layer of the Bleached Earths can be the uppermost soil stratum of a weathered rock.

Further, the author is acquainted with many examples in which there are signs of a conversion of Brown Earths into Bleached Earths under the

Numerous analyses of the Brown Earths are available but there is a surprising lack of investigations of complete soil profiles, which provide an insight into the processes of weathering.

The bedding of the Brown Earths displays an upper soil (A) containing small to moderate quantities of humus, usually only slightly differentiated from the subsoil (B). The substratum (C) in soils which have arisen from the weathering of exposed rocks, is usually mixed with angular fragments of rock, which become more numerous at lower levels, so that a layer of "brash" often covers the parent rock.

The climatic conditions prevalent in the districts of the Brown Earths favour the slow downward movement of the soil in coherent masses on the slopes of mountains ("creep").

The Brown Earths, as a result of the influence of the parent rock and of situation, have many local soils, which frequently vary within short distances. Basalt dikes, veins of diabase and similar detached formations often carry soils which differ greatly from the types in the neighbourhood. On examining the works of Fallou and Grebe[75] we find that it is mostly "ferruginous loams" and "ferruginous clays" which result from the weathering of the rocks, i.e. Brown Earths. Decidedly Sandy Soils having the character of the Brown Earths apparently do not occur. The rainfall in the area is probably sufficient to deprive Sandy Soils of their soluble substances and in this way bring about the formation of easily dispersed humus compounds, and so eventually of Bleached Earths.

Calcareous Soils. The soils formed by the weathering of

influence of injurious forms of humus and a change in the vegetative covering (e.g. Pines in place of pre-existent broad-leaved trees, heather and the ground flora in place of other forms of leaf-litter). This is shown by the soil becoming bleached in places where there is a greater flow of water, rotting roots, etc. Not uncommonly small spots are found which, surrounded on all sides by sour humus, are bleached, or a thin layer on top of the soil is completely transformed into Bleached Earth. Such occurrences are spoken of as "weakly podsolic" by the Russian investigators. These transformations of Brown Earths into Bleached Earths are to be classified in the same way as the Degraded Black Earths.

calcareous rocks occupy a special position amongst the Local Soils of the Brown Earths. Whereas the silicate rocks only lose a small proportion of their bulk during weathering, the calcareous rocks lose their calcium carbonate as a result of the solvent action of the water containing carbon dioxide, so that the soils are mostly composed of the material which is mixed with the calcium carbonate; this results in the most varied soils being formed from the weathering of calcareous rocks. The purer a limestone, the less residues remain and the soil formed is usually shallow, poor in fine earth, on the other hand, rich in fragments of limestone.

Many limestones contain an admixture of hydrated silicates of aluminium (clay) in a very fine state of division, so that on weathering heavy soils are formed. In decidedly moist districts the upper layers are not uncommonly distinctly deficient in calcium carbonate or even free from carbonates as a result of excessive leaching. The Leached Soils then undergo those changes which are characteristic of the prevailing climate. In arid climates all soils contain sufficient calcium carbonate to display the characteristics of Calcareous Soils. A Black Earth on limestone for instance is only to be distinguished from any other Black Earth by the presence of fragments of limestone in the lower layers of the soil. "Calcareous Soils" as a local type which differs from the soils of a district are only found in a moist climate. Nevertheless, if Calcareous Soils are to be separated from other types, this is mainly due to the following facts:—

Exposed calcareous rocks are almost certainly greatly fissured and are therefore well drained. Hence, the calcareous formations of all climates are remarkable for the peculiar behaviour of the water. The rain rapidly penetrates into the cracks and then flows down through channels formed by the solution of the limestone and forms subterranean water-courses, which often emerge as huge springs. This type of erosion by water has been named "Karsting," after the Karst district of Austria where it is strikingly well developed and where it was first thoroughly investigated. As a result of the removal of the water in underground streams the rising

current is restricted to that portion of the soil water which does not drain away, but remains in the soil (the capillary water). This is usually a very small quantity. The majority of Calcareous Soils are therefore not influenced by the ground-water, and on account of the rapid removal of the seepage water to great depths rarely suffer from water-logging. The plant covering, on the other hand, frequently suffers from an insufficient supply of moisture. The water content of the soil affects the soil temperature. Wet Soils are "Cold Soils" on account of the high specific heat of water and the absorption of heat on evaporation. Drier Calcareous Soils on the other hand are "warm soils." This, as well as the peculiar type of humus formation, is an important reason for the generally observed phenomenon that soil types of warmer climates penetrate furthest into cooler climates on limestone.

In accordance with their jointing, calcareous formations usually have steep slopes, the rock being often freely exposed on escarpments and cliffs, and therefore exposed to great changes in temperature. It becomes very warm when the temperature is high, while at low temperatures the radiation, and hence the cooling, is considerable. Evaporation is increased at times of high temperature; this results in cliffs and slopes exposed to insolation having a definite soil climate. Limestone districts hence often have conspicuous Reef Soils (Randböden) of an independent character.

Limestone Soils have a neutral or slightly alkaline reaction. The calcium carbonate content prevents the hydrolytic dissociation of the silicates leading to the formation of free acids, for an excess of easily decomposed calcium carbonate is sure to be present.

Humus formation on Calcareous Soils often leads to the deposition of black humus substances. The rôle of calcium carbonate in the decay of organic matter has not yet been established. Many of the bacteria active in the soil prefer soils which contain calcium carbonate; crumbly, well aerated soils favour decay; we know from experience gained in the reclamation of moors that the decay of peat is promoted by the addition of calcium carbonate. On the other hand, black

humus accumulates with an abundant supply of calcium carbonate, so that a high humus content is a phenomenon which is characteristic of many Calcareous Soils. Our knowledge of the processes of decomposition of organic residues has not yet reached a stage that will enable us to explain these relationships. Calcium carbonate prevents the formation of dispersible humus colloids, hence, in well aerated Calcareous Soils, "acid humus" is not formed with all its "protective colloid" actions. It may be concluded from the available analyses that the decay of organic matter in the presence of sufficient quantities of calcium carbonate leads to the formation of a humus which is richer in carbonates than that formed in a soil deficient in calcium carbonate. Taking these relationships into consideration, the mode of accumulation of humus in the Arid Black Earths must be distinguished from that in which calcium carbonate alone is concerned, for in the former case climatic reasons are known which retard the decay of the humus. Numerous soils arising from the weathering of calcareous rocks are deficient in humus, while others contain large quantities.

A Calcareous Soil that contains large quantities of humus is called Rendzina in Poland, by which is understood a rather heavy clay. Recently under the influence of Russian soil workers the term "Rendzina" has been applied to all soils which have developed from the weathering of calcareous rocks; this is not to be recommended, since Calcareous Soils vary too greatly in their properties to justify a common genetic designation.

In Calcareous Soils the ferric hydroxide content is found to be reduced in the top soil (A) and increased in the subsoil (B). Hence a translocation of iron has taken place from above downwards. The processes by which this is effected have not yet been explained. In many instances the fact is brought into prominence by a difference in colour between the soil and the subsoil. The soil is often, even with only a moderate humus content, surprisingly dark in colour or, as in most German Calcareous Soils, bright dun, brownish-yellow to brown tints prevail. The subsoil (B) is always darker in

colour than the soil, yellow-brown, brown, often red-brown to red.

Amongst the soils which have arisen from calcareous rocks we must also include the loams of the Northern Glacial Deposits so far as these have originated from unaltered Glacial Marl, i.e. Glacial Marl which has not been denuded of its fine earth constituents by leaching.

The Red Soils of the Karst (*Terra-rossa*).

The Calcareous Soils of the Northern Mediterranean districts known as Terra-rossa form a continuation of the Calcareous Soils of Central Europe. Up to the present the author has not had an opportunity of thoroughly investigating these Red Earths. So far as his examinations extended the soils known as Terra-rossa should be separated into two types.

The one form is dominant on the Table-lands of the Karst and of the limestone formation as far as Croatia, and probably extends further to the South in the Balkan Peninsula. The soil is dun, yellow-brown to red-brown, the subsoil brownish-red to dark-red.

The second form of Terra-rossa consist of Reef formations, which are found as red and reddish-brown crusts on the calcareous rocks and accumulate in cracks and depressions forming brown-red masses. The slopes and crags of the mountains owe their remarkable red colours—which surprise every tourist—to the separation of large quantities of ferric hydroxide on the limestone rock.

The first form of the Karst Red Earths is doubtless continuous with the Calcareous Soils of Central Europe, from which they are mainly distinguished by the subsoil being more deeply coloured. It is possible that the soils of the Karst Table-lands are old soils, whose formation dates back to the Diluvial Period, and whose properties are partly due to a cooler and moister climate than that prevailing at the present time. The question of age must always be borne in mind in the case of soils which were not covered by ice during the Glacial Period. Calcareous Soils, whose formation must involve the

removal of several, often many, metres of rock, can hardly have been formed in the short time which has elapsed since the retreat of the glacial ice.

The Reef Red Earths acquire their characteristic properties through the high temperatures of the soil and the intense dessication during the dry season. The formation of organic matter is not significant on slopes which are deficient in water during summer, while the mild winters bring about a rapid decay of the organic residues. Hence the soils have a low humus content and display the brilliant colours characteristic of soils poor in humus.

Probably we shall not go very far wrong if we regard the Reef Red Earths of the Mediterranean districts as semi-humid formations. The rains during the cold half of the year are sufficient to leach the soil; the seepage water penetrates to great depths through the cracks, the ascending currents produce only trifling effects. Hence the soils have the main characters of humid soils, though their nature is influenced by the high temperatures and intense dessication during the warm season.

Up to the present the Karst Red Earths have been little investigated, attention having been mainly directed to the Reef formations. Many different opinions have been expressed as to the origin of the iron in these soils, but no definite satisfactory conclusion has been reached.[76]

The Moist-Dry (Semi-Arid) Soils of the Temperate Zones

In continental districts the contrasts between the warm and cold seasons are very pronounced. The winters are cold; frost penetrates to great depths in the soil; the soil is frozen for a number of months. On the other hand, both air and soil-temperatures are high in summer; the powerful insolation often raises the temperature of the surface soil to over 60°C. The saturation deficit of the air is considerable, and evaporation is consequently very great. In summer, therefore, the soil is

dried out to a great depth and the upward movement of soil moisture becomes very marked.

In Winter, the rainwater accumulates in the soil and provides for a luxuriant Spring vegetation. Drainage water is only formed in trifling quantities in these soils, though the large proportion of the rain which soaks into the ground in Winter is sufficient to saturate the soil to a depth of several metres. During the warm season the water again rises into the drying upper layers. This behaviour of the water is perhaps the most characteristic feature of Arid Soils.

The soils of districts with a periodic climate are thus exposed to humid conditions during the cold season, to arid conditions during the hot season. The long period of frost in Winter and the almost equally long period of intense desiccation in Summer, retard the decay of the organic residues. The luxuriant vegetation in Spring, as well as the great development of the root system which is peculiar to species successfully adapted to dry situations, provide large quantities of organic matter, so that the soils formed are rich in humus.

The soil properties are determined by the agencies at work in the Summer season, which impress on the soils those features characteristic of arid zones and regions.

Climatic conditions more or less similar to those described above, prevail in Europe over vast expanses of country of very uniform relief, so that similar soils are formed over enormous areas.

The typical soils of this climatic zone are the *Steppe Black Earths*, of which the Black Earth of Eastern Europe, the Tschernosem, has been most thoroughly investigated.

The Tschernosem has a very wide distribution and extends (although intersected by mountains with their characteristic Local Soils of higher regions in many places) from Manchuria in the East throughout Siberia, Central and Southern Russia to the Carpathians. It is also found in Roumania, covers considerable areas in Hungary and stretches in smaller or larger tracts through Moravia and Bohemia to the centre of

Germany (Magdeburg Border, Hildersheim).* Similar soils are widely distributed in North America and in some parts of South America.

The Steppe Black Earths are one of the most pronounced climatic soil formations; they occur on the most varied kinds of rock and have the same character and a similar profile in all the localities of their far-reaching occurrence.

The Tschernosem contains large quantities of humus which has no recognisable organised structure and is uniformly mixed with the mineral portion of the soil. The average humus content is about 6 per cent., though larger quantities may be present, locally often rising to, or even exceeding 12 per cent.

The soil is loose and very crumby; the colour is deep-black; the humus content decreases from above downwards. The humus layers are often of great thickness, 70 to 100 cms. being common. The lower soil (A_2 of the Russian investigators) is irregularly coloured, dark veins and patches are found alongside the usually light brown or yellow-brown deeper rock. The humus layer merges into bed-rock in the lower layer of the soil without any sharp division.

Deposits of calcium carbonate are found at varying depths in the soil, often in the form of concretions; a layer containing gypsum usually lies beneath the carbonate stratum. The Tschernosem is also characterised by the frequent occurrence of the burrows of animals which live in the soil; these remain recognisable for a long time as they are usually filled later with earth of a different colour.

The Tschernosem's content of acid-soluble ingredients is high. Analysis of the separate layers of the profile show that transferences only take place to a slight extent in the soil. For the most part, the only concentrations encountered consist of deposits of calcium carbonate and calcium sulphate.

The following figures from Glinka, calculated on soil free from humus and carbonates, afford an example of the constancy

* The Black Earths penetrate furthest into humid districts on Loess, in the same way that Red Earths penetrate into cooler districts on limestone, and Podsol into warmer localities on Sand. It is concluded that the great mobility of water in Loess favours the formation of Black Earths.

of the composition of the different layers of the Tschernosem.[77] At the same time they give an insight into the high content of Arid Soils in plant nutrients.

	Tobolsk		Siberia		
	A	C	A_1	A_2	C
SiO_2	71·74	71·73	65·55	65·45	65·53
Al_2O_3	15·19	14·81	17·84	19·22	18·56
Fe_2O_3	5·30	5·59	6·84	6·00	6·84
CaO	1·70	2·07	3·84	2·99	3·05
MgO	1·97	2·77	2·30	2·44	2·31
K_2O	1·87	1·78	2·47	2·29	2·45
Na_2O	1·79	2·20	1·54	1·69	1·57

On the borders of the Tschernosem the black colour of the soil gives place to a greyish or grey tint which becomes the more marked, the more arid the climatic conditions. It is probable that this grey colour is connected with the formation of soda in the soil; as, indeed, the Grey Steppe Earths also owe their colour to the action of soda.

Grey colours are also found on the borders of the more humid districts, as in Russia on the borders of the Northern Grey Earths, which become dominant in the "Degraded Tschernosem" and the colour of which can be attributed to the removal of iron by acid humus substances. These grey soils form a transition to the Bleached Earths.

The Prairie Soils of North America are divided up by the American investigators into a number of geographical groups.[78] In the main the Prairie Soils correspond to the Black Earths of Europe, with which they agree both as regards profile and properties. A more detailed classification is probably required before a full comparison can be made with the soils of the old world.

In the Western Prairies large areas of Brown to Red-brown Soils are found which, from the descriptions, correspond to the Chestnut-Brown Soils of Southern Russia and Central Asia, which are there connected with the Grey Steppe Soils. In the Steppe areas of North America exposures of crystalline rocks apparently do not occur, but Steppe Bleached Earths

are found on sandstones and schists, and widely distributed on Loess, Loams and Clays. Often it is doubtful whether the classification adopted corresponds to that employed in Europe. For instance, for the Oklahoma Group of Prairie Soils, it is stated that the upper soil is red to almost black, the subsoil in most cases red, the substratum certainly red. On limestone Dark Brown to Chocolate Brown Soils occur on a red substratum, etc.

The Chestnut-Brown Soils.

To the South of the Asiatic Black Earths on the East of Europe, there is an extensive belt of soils coloured brown by humus which from their colour are known as the Chestnut-Brown Soils. These are particularly common on the Asiatic borders of the Black Earths; soils with the same properties are found in the Walachei[79] and in separate parts of Hungary.

The Chestnut Brown Soils form a series which is continuous with the Tschernosem which they represent in drier regions. Increasing aridity reduces plant growth and consequently the quantity of humus in the soil decreases. The humus substances differ not inconsiderably from those of the true Black Earths; the colour of the organic ingredients of the soil is yellowish to deep brown, and black humus is not found. In the present imperfect state of our knowledge of humus, the fact must be accepted that under the given climatic conditions the process of decomposition of organic residues is different from that in moister districts and results in the formation of a different kind of humus. The soils are rich in carbonates, the deposition of which frequently reaches the surface of the soil so that the ground effervesces on being moistened with dilute acid. The rule, valid for less dry districts, that dark black humus substances are formed in Calcareous Soils does not hold for these arid districts.

The Chestnut-Brown Soils have a moderately loose topsoil. Lower down the whole soil is permeated by cracks so that the soil when broken falls into prismatic fragments varying in size. The substratum contains large quantities of calcium

carbonate and on this account is light (often whitish) in colour.

The upper layers of the Tschernosem and of the Chestnut-Brown Soils have a low content of water-soluble constituents; on the other hand, the ground-water is usually highly impregnated with salts and is slightly to decidedly brackish. Apparently there is a sharp division between the soil-water which is deficient in salts and the ground-water which is rich in salts.

The author had an opportunity of investigating this separation at Tschernomorje in Tauria. Oaks had been planted around a salty moist shallow depression carrying Tamarix taurica, and the growth of the oaks was found to increase with the elevation of the ground. This appeared to be a favourable opportunity to determine the limit of salinity which the oak would tolerate. Trial holes showed that the water-table stood everywhere at the same level and agreed with the height of the water which accumulated under the Tamarix bushes; the latter was thus an instance of the emergence of the ground-water. The growth of the oaks became the more vigorous the thicker the layer of soil above the water-table. The soils, as shown by analyses carried out later, had roughly the same low content of water-soluble ingredients. Here, again, we have an instance of the common occurrence of soil-water having a low salt content floating on ground-water or telluric water having a high salt content without the two becoming mixed. The diffusion of salts in the soil takes place too slowly to bring about a uniform distribution.

Glinka includes the Chestnut-Brown Soils in the Semi-Deserts; it seems to the author from what he has seen that it would be more suitable to regard the Chestnut-Brown Soils as a sub-type of the Steppe Soils, in fact, as a well defined sub-division of the Humus Steppe Soils. It is always difficult to define the limits of a vague expression such as "semi-desert." In Soil Science the "Semi-Desert" should start with the occurrence of calcareous incrustations and similar deposits.

With the progressive increase of more arid conditions towards the inner portions of Central Asia, Brown Coloured

Soils are found which Glinka calls "Brown Earths."[80] Although the humus content of these soils is at the most 1 to 2 per cent., this is sufficient to give the soils a brownish colour. These soils are continuous with the Humus Steppe Soils, of which they are the type having the lowest humus content.

It will be advisable not to employ the term "Brown Earths" for these Arid Soils coloured by brown humus substances. They differ fundamentally from the Brown Earths of Central Europe, which are coloured by ferric hydroxide. Glinka's argument in favour of the independence of the soil type which he has called the "Humus Brown Earths," is that they are formed under more intensely arid conditions than the rest of the Humus Steppe Soils. From the available reports, the division between the Chestnut-Brown Soils and Glinka's "Steppe Brown Earths" does not seem to be a sharp one, the transition appearing to take place step by step. If this is so, we are dealing with a sub-division of the Chestnut-Brown Soils.

The Humus Steppe Soils are a series of soils which, formed under a periodic climate, mainly owe their properties to the ever-increasing aridity of the climate in Summer. At the same time, the total rainfall diminishes and this also increases the dryness of the zone. The Humus Steppe Soils are distinguished from the second series of Steppe Soils, the Steppe Bleached Earths, by the upper layers of the soil having a lower content of soluble salts, as well as by the slight influence exercised by sodium carbonate (soda) on the soil properties. Traces of soda must be formed in all Calcareous Soils and these become evident by the bleaching and the removal of the iron brought about by soda in soils containing humus. Even in the Tschernosem slightly greyish tints are seen; these become more marked in a drier climate and finally lead to the formation of a variety of Bleached Soils—the Steppe Bleached Earths or Grey Steppe Soils, which are the dominant soil-type over vast expanses of arid regions.

The Steppe Bleached Earths.

One of the most striking phenomena of soil formation is the bleaching of the soil, that is the removal of the iron. Up

to the present three processes are known by which this is brought about:—

1. The action of *acid* humus colloidal bodies, which is responsible for the formation of the Northern Bleached Earths.

2. The action of colloidal humus bodies in Alkaline Soils containing soda; this leads to the formation of the Steppe Bleached Earths.

3 The action of strong mineral acids, particularly sulphuric acid; a process which is of less importance than the first two, but is probably of greater significance in the formation of Local Soils than is generally recognised.

It can be assumed that bleaching of the soil takes place in all arid and semi-arid zones under the influence of alkaline solutions of humus, although the intensity of the action varies within wide limits. The necessary conditions for the process are also provided on Calcareous Soils in a moist temperate climate. If the concentration of soda in the soil is very low, no visible effect is produced; but with increasing quantities the soils assume a slightly greyish hue. It is only with a comparatively high concentration that the iron is completely removed. The behaviour of the Tschernosem illustrates these relationships; the drier the climate the more marked is the grey colour of the soil (especially when dry) until finally in the Steppe Bleached Earths the action of the soda brings about a complete bleaching of the soil.

Under the influence of the alkaline carbonates the crumb structure of the soil is destroyed and the soils are deflocculated. This action is usually attributed to the hydroxyl ions of the alkaline solutions; it is doubtful whether this is correct. Very slightly dissociated solutions of ammonia exert a powerful deflocculating action, while highly dissociated solutions of the hydroxides of the alkaline earths are even at very low concentrations some of the most active flocculants known for Deflocculated Soils.[81]

The important fact is that a content of soda brings about a

puddling of the soil, while sodium bicarbonate, on the other hand, has but little effect. Sodium bicarbonate preponderates in the lower levels of the soil on account of the larger quantities of carbon dioxide present in the soil atmosphere. Hence in the soil the action of soda on the soil has three phases. In the upper soil colloidal solutions of humus are formed, particles of ferric hydroxide and clay become mobile and are carried down by the percolating water. In the subsoil the bicarbonate is formed; this results in the precipitation of the colloidal solutions, and clay together with humus accumulates. There still remains sufficient sodium carbonate to make the structure of the soil very compact, but not sufficient to maintain the colloidal material in a mobile condition. In the substratum the bicarbonate is so greatly in excess of the carbonate that the soil remains loose and crumby.

The action of soda in the soil may be summarised as follows: In small quantities it brings about the destruction of the crumb-structure and the consolidation of the upper layer of the soil. In larger quantities it causes the formation of a highly compact middle layer by the removal of the colloidal constituents from the upper layers.

With a low soda content the soils are compact, on ploughing they break into coarse clods, as for instance is frequently found in many of the heavy soils of Hungary. If the soils contain large quantities of humus they are distinguished from the Steppe Black Earths by their close compact structure and absence of crumb formation. With a lower humus content, or a higher one of soda, the upper layers of the soil become bleached and form unmistakable Bleached Earths.

Grey Steppe Soils or Bleached Earths are the dominant soils of Central Spain. Glinka describes their occurrence in Turkestan and Trans-Caucasia. In North America they are widely distributed in the arid West and are responsible for the characteristic grey colours of the landscape.

The Grey Steppe Soils merge into the Saline Soils, with a varying, but always high content of water-soluble salts.

Saline or Alkali Soils.*

A number of investigations have been carried out within recent years on soils containing salts; their occurrence is greatly dependent on the rate at which drainage takes place, so that it is usually local conditions which determine whether a soil contains salts or not. Depressions and hollows frequently have saline soils while the surrounding soils at only a slightly higher elevation are free from salts. The accumulation of salts is closely connected with a brackish ground-water and with a run-off of the surface water which collects in the hollows. In districts of intense evaporation Saline Soils occur to a much less extent in the form of large continuous areas than as small local patches and in situations which favour the collection of water. Glinka justly remarks "these soils generally develop in connection with the same type of relief as the Moor and Heath Soils of moister districts."

Saline Soils are therefore often Local Soils. The alterations which result from the action of salts in the soil, as well as the dependence of the accumulation of salts on the climatic conditions, however, justify us in including the Saline Soils in the list of climatic soil types.

Saline Soils are very diversified, their colours vary greatly and may agree with those of the surrounding soils, although on the whole greys predominate. The Saline Soils are defined by their high content of water-soluble salts, the alkaline reaction of the soil solution and the consolidation of the subsoil (horizon B).

The salts present in Saline Soils vary both in quantity and composition within wide limits. Of the salts found, soda exercises by far the greatest effect on the soil. This action has already been considered in the case of the Grey Steppe Soils it depends on the varying equilibrium between sodium carbonate, sodium bicarbonate, and the carbon dioxide content of the soil atmosphere. With an increase in the carbon dioxide content the hydrolytic dissociation of the sodium carbonate

* Rastall (*Agricultural Geology*, p. 157) proposes that the term "Alkali Soils" should be applied to these soils, and that "Saline Soils" should denote Semi-Desert Soils, here called "Crusting Soils," p. 106.—(C. L. W.)

into carbon dioxide and sodium hydroxide is depressed, so that in the lower layers of the soil the bicarbonate is in excess, and this on rising to the upper layers of the soil is split up into sodium carbonate, carbon dioxide and water.

The course of the changes is therefore as follows:—During the dry period, the soil-water containing sodium bicarbonate in solution rises; the acid salt decomposes on coming in contact with the atmosphere of the upper soil which has a low carbon dioxide content, and sodium carbonate is formed. This salt exerts a deflocculating action on the finer particles and a solvent action on the organic portion of the soil. At the next fall of rain the colloidal solutions of humus-clay-soda soak into the soil and in the subsoil come in contact with a soil atmosphere containing larger quantities of carbon dioxide; the bicarbonate is formed, and the colloidal substances which are only soluble in sodium carbonate are precipitated and consolidate the subsoil into a tenacious mass which is impervious to water. The upper soil remains as a layer which is rich in silica, and poor in clay, iron and humus, and which is sharply differentiated from the tenacious coherent subsoil. When the soil dries, the top-soil forms light (according to weight) friable masses which are often stratified or permeated by round gas pores. The heavy subsoil, on the other hand, on drying breaks down into prismatic fragments, often arranged in columnar fashion. The higher the soda content, the more marked is the jointing in the soil structure. A higher content of chlorides and sulphates reduces the effect of the soda.

Saline Soils everywhere have the same structure. Russian investigators discriminate between two types of Saline Soils: (*a*) Solutschak, soils with less pronounced soda action, and without columnar subsoils, and (*b*) Solonetz with columnar (or irregularly aggregated) structure of the subsoil.

The Saline Soils of Hungary exhibit the structure described above. The heavy clay varieties are there known as Sik Soils (Hungarian = Szek).

The Saline Soils known as "Alkali Land" cover large areas in North America; they are common West of the 90° meridian of longitude. Numerous investigations have been

made on the American Saline Soils. According as soda is present or not, they are distinguished as Black Alkali and White Alkali. The names are derived from the colour of the efflorescent salts. The consolidated layer of the subsoil is known as "hard pan."

The bulk of the salts occurring in Saline Soils consists of mixtures of the chlorides, sulphates and carbonates of sodium, magnesium and calcium. Occasionally individual salts predominate. The quantity of salts in the soil varies within broad limits. As a rule, the consolidated subsoil has the highest content of soluble salts. During the course of the year the salt content may vary in the separate layers of the soil; this is mainly connected with movements of water in the soil. The height of the water-table is of great importance. The ground-water is brackish, and the higher it stands, the greater is the quantity of salts carried into the upper layers of the soil as a result of evaporation and of capillary rise of the water. If the crystallising concentration is attained the salts effloresce on the surface. In irrigated districts the level of the water-table has often risen with the result that efflorescences now occur in areas which formerly were free from salt. This has been experienced in North America, India (efflorescences there known as Reh), and also recently in Egypt (and Mesopotamia). The damage wrought by the occurrence of salt efflorescences is often of considerable economic importance.

Sub-Tropical Soils

Up to the present the Sub-Tropical Soils have been but little investigated. According to the work which has been published so far, three types in particular call for recognition; Red Earths, Sub-Tropical Black Earths and Crusting (or Saline) Soils.

The Yellow or Ochreous Soils known as Yellow Earths form a transition between the Warm-Temperate and the Sub-Tropical Soils. These were first recognised in the South of France and are also found in the Atlas and in Japan. No investigations have been reported on these soils which merge into the Red Earths.

The Sub-Tropical Red Earths are to be distinguished from the Karst Red Earths which are confined to calcareous rocks, while the Sub-Tropical Red Earths are found on different kinds of rock. The bright red sands of the desert exhibit a thin ferruginous coat surrounding each individual sand-grain, which cannot be removed by mechanical means but dissolves in hydrochloric acid.

The position of the Red Earths in the soil classification is uncertain. The author has seen Red Earths in Spain with horizons of calcareous concretions, occurrences which denote arid or semi-arid conditions of formation. On the other hand many of their properties indicate a semi-humid origin.

The Red Earths are deficient in humus and organic matter, the lack of which determines the pure brilliant colours of the soils. High temperatures in Summer and moderate ones in Winter bring about an accelerated decay of the organic matter so that the accumulation of humus is suppressed or only takes place to a very limited extent.

The Sub-Tropical Red Earths are widely distributed; they probably occur in every district of this climatic zone. Unfortunately investigations on the structure, and analyses of soil profiles have not been published. Further and more detailed investigations are urgently required.

The Sub-Tropical Black Earths. Black Earths are found in different countries in the sub-tropical zone but under similar climatic conditions, frequently covering large areas. The best known tracts are the Regur of India and the Black Earth of Morocco. Other examples have been cited from the South of Spain and Calabria. The status of the soils of the Southern Prairies of North America has not yet been established; they may be grouped here or may belong to the Steppe Black Earths of the temperate zones.

A certain amount is known about the Regur or Black Cotton Soil of India, which is formed under semi-arid conditions. Von Richthofen points out that in the tree-less Regur districts there is a very great difference between the wet and dry seasons. Regur occurs on various formations (Basalt, Limestone, Gneiss), and from this is clearly a climatic soil type.

In India it covers at least 200,000 square miles, but also occurs in isolated patches which are sharply differentiated from the surrounding Red Soils.[82]

The colour of the Regur varies between dark grey and deep black.

The soil is plastic when wet, but on drying breaks down into fine crumbs with the least pressure. The dark colour is caused by organic matter with a high carbon content, which is distinguished from the humus found in other climates by the difficulty with which it is decomposed. (On Basalt titanium dioxide also plays the part of a colouring ingredient in the soil).

Very characteristic of these soils are the great changes in volume which accompany variations of the water content. During the dry season cracks are formed which are often 12 to 15 cms. broad and one to two metres deep.

In Morocco the Black Earths are distributed along the Atlantic coast. They are known as "tîrs" and occupy the depressions, whereas the more elevated areas are covered by Red Earths (hamri). The humus content is low (2·5 to 3 per cent.) According to the available descriptions these soils agree with the Regur of India both in structure and properties.[83]

In North America the Prairie Soils of the Gulf Group probably belong to the Sub-Tropical Black Earths; at least from the descriptions they agree better with these than with Black Earths of temperate zones. The physical properties, especially the deep fissuring during the dry season, are clearly shown. On drying, portions of the upper soil break off and fall into the cracks. The increase in volume during the following rains leads to upheavals of the soil which bring about the formation of shallow depressions, often 30 cms. deep and a metre broad. Their resemblance to the excavations made by pigs has resulted in these areas being given the more vivid than poetic name of "hog-wallow land."

Crusting (*or Saline*) *Soils*.* have up to the present been described mainly from the Southern Mediterranean countries. Under the influence of the dry climate the soil-water rises

* See footnote on page 102.

rapidly and reaches the surface of the soil; the soluble and decomposable substances separate out and often form thick crusts on the former Mineral Soil. Calcium carbonate predominates in these crusts, but gypsum and ferruginous strata are also found close to the surface.[84]

Protective crusts are often formed on the surface of rocks in Deserts. They have been designated "Desert-lac." They are of little importance in Soil Science on account of the trifling thickness of the layer.

Crusting Soils occur in all semi-deserts and are also present in deserts. As a rule they attain their greatest dimensions in districts having intermediate climates, decreasing towards humid districts as well as towards the true deserts.

Desert Soils have been little investigated up to the present. The colour of the soil appears to be mainly dependent on the colour of the parent rock. Blanckenhorn remarks that yellowish-grey, yellowish-white, yellowish-red or snow-white colours predominate rather than red.[85] In the desert, chemical weathering is restricted mainly to those portions of rocks which are frequently moistened by dew. High temperatures and intense evaporation cause the soluble salts formed to crystallise out actually beneath the surface of the rock, so that a thinner or thicker layer of only slightly decomposed or even unaltered rock remains, while the deeper layers are completely decayed. If the solid surface is broken, the wind can blow away the inner portion. It may be remarked that this "Desert-Weathering" can also take place in a temperate climate on Local Soils. This occurs for instance on the Quader Sandstone of the Elbe sandstone districts[86] and on many Bunter sandstones which are freely exposed to sun and wind. The process is of great economic importance as regards the durability of stones used for building purposes, which exposed to smoke rich in free sulphuric acid and hot gases, are subject to "Desert-Weathering" on the most minute scale.[87]

The Soils of the Tropics

The scientific investigation of Tropical Soils has only just commenced but it has already shown that there is a greater

variety of soil types than was assumed previously. Enormous areas, such as the great forests of Central Africa and South America are almost, if not quite, unexplored as regards their soils. The tropics as compared with other climates show very great effects due to the weathering agencies. The high temperature speeds up the chemical reactions, and the heavy rainfall accompanied by intense evaporation causes an enormous circulation of the water. In addition we have the influence of the age of the soil. Many tropical countries are ancient continents; even though the removal of the products of weathering takes place on such a large scale, the abrasive agents of the Glacial Period which metamorphosed the soils of the Northern Hemisphere are absent. In the tropics the elevation of the country above sea-level provides much more varied conditions for the formation of soils than do similar elevated tracts in higher latitudes. For instance, in 50° N. latitude, between sea-level and the snow-line the only possible climates are those which range from temperate to frigid. In lower latitudes all gradations from tropical, through sub-tropical, temperate, sub-arctic to arctic may be met with. Large areas of the tropics are under the influence of a periodic climate, which, with its wet and dry seasons, has at least an equal significance for soil formation to the change from summer to winter in high latitudes.

The difference between a hot and a temperate climate becomes most marked with respect to the formation of humus. Under uniformly high temperatures the decay of organic residues takes place rapidly and generally results in the upper layers of the soil being deficient in humus. Large quantities of organic matter are synthesised in the fertile districts of the tropics; hence the equilibrium between the building up of organic substances and their decay determines whether the soils are rich or poor in humus. Readily dispersed humus colloids may also be formed in the tropics, under conditions of intense leaching and on soils deficient in bases. These must bring about a bleaching of the soil in a similar manner to that known in the case of the Northern Bleached Earths. So far little is known and less has been recorded about the influence

of the plant covering on the soil climate, which, particularly in the case of the primeval forest, must be very great.

The nature of the river water provides evidence for a critical examination of the question as to whether Bleached Earths occur on a large scale in the tropics. All rivers draining districts of Bleached Earths have dark waters, coloured by humus substances (Black Water); they are "Black-water rivers." The tropical rivers draining the great forest areas have black waters. This holds for the rivers of Central Africa and perhaps to a still larger extent for those of South America. Hence it is probable that the soils of the dense primeval forests of the tropics are Bleached Earths on a large scale. If this is so, they should then be known as the Tropical Bleached Earths.

The principal soil types of the tropics are Laterite and Red Earths.

Laterite.

The term Laterite (*later*—a brick) is due to Buchanan, who gave this name to an Indian soil containing large quantities of iron, which, cut into pieces and dried in the sun, is used as building material by the natives. The term Laterite was afterwards applied to all Tropical Soils rich in the hydroxides of iron and aluminium. It is only recently that we have commenced to discriminate more closely, but in spite of a large amount of work the phenomena displayed by Laterite and the conditions which determine its formation are not yet explained. The views expressed are often contradictory, and it is even a matter of doubt and controversy as to whether Laterite formation is still taking place at the present time, or, considered geologically, is at an end.[92]

Typical Laterite is described as an earthy soil, permeable to water, and brick-red to carmine or yellow-brown in colour, sometimes with lighter coloured or whitish patches. Laterite resembles clay, but can be distinguished from true clay by its non-plastic nature, such that it can be crumbled easily between the fingers. The structure of Laterite is cellular, softer portions being surrounded by a coarsely meshed network. If these

harder portions become enriched in iron they often change into remarkable iron concretions which frequently have a lustrous slag-like surface.

Laterites are intensely Leached Soils whose content of the hydroxides of iron and aluminium has been preserved and probably increased. The ferric hydroxide remains in the amorphous state; aluminium hydroxide crystallises out and occurs as hydrargillite ($Al_2H_2O_4$) in microscopically small crystals. Hydrated silicates of aluminium (clays) are not entirely absent from Laterite but they are present only in greatly reduced quantities. Quartz remains unaltered and mixed with the soil in the formation of Laterite, on the other hand, all soluble substances are washed out. The soluble silica is often reduced to a small percentage; as a rule only traces of calcium and sodium are present, while potassium and magnesium are retained in rather larger quantities.

Laterite arises from the weathering of very different rocks (Granite, Diorite, etc.) and should therefore be distinguished as a distinctly climatic soil type. The thickness of Laterite is usually considerable, it often forms beds several metres thick. The iron content as a rule decreases from above downwards, the colour becoming lighter and passing over into yellow.

Tropical Red Earths. Red Loams.[88] Even less progress has been made in the investigation of these soils than with the Laterites. The Laterites have a distinctive feature in their cellular structure, while the Red Earths and Red Loams are named after their colour; further they have been described as occurring in districts of very different climates. It is therefore very probable that "Tropical Red Earth" is a collective name including Tropical and Sub-Tropical Soils which have not yet been differentiated.

Savannah Soils.

Savannahs are tree-steppes: districts in which the trees do not form closed woodland, but are more or less isolated, while the intervening ground carries other vegetation, principally reed-grasses (Orchard-bush).

The Savannah Soils have only recently been investigated and in the case of the Climatic Savannah have an independent character.[89]

Two soil types are to be distinguished in the African Savannahs, the Climatic Savannah Soils and the Degraded Forest Soils.

Districts having a climate which leads naturally to the dominance of true Savannah are characterised by a heavy rainfall within the duration of a few months, which transforms the country into a morass and saturates the soil to a great depth, and a long dry period during which the soil dries out to a great depth.

With these Savannahs are contrasted large areas which climatically belong to the tropical primeval forest and whose soils have lost their original character under the influence of Man's "land-robbery." Most Tropical Soils are deficient in plant nutrients and are in great need of manures. The foliage, which falls continually throughout the year, decays rapidly and the liberated plant nutrients are at once absorbed by the roots of trees, with the result that a comparatively small quantity of nutrients circulating very rapidly suffices for the great luxuriance of the tropical forest. On the whole, the tropical forest works with a small capital of nutrients and a rapid turn-over. Small encroachments on the forest heal quickly so long as the soil retains its old character. Also Savannah fires do little damage to the closed forest, as Metzger emphatically points out.[89]

The conditions are greatly changed under the destructive system of cultivation adopted by the African natives. The forest is burnt down to provide land for cultivation. As a result of this system the nutrient salts present in the plants are rendered soluble and to a large extent are lost from the soil by leaching. When it is no longer possible to obtain a crop, the field is abandoned and allowed to revert to bush and then is again made available for cropping by burning off the scrub which has grown upon it. This process is repeated so long as a crop can be obtained. The final result is not only the exhaustion of the soil, but the destruction or diminution in

number of the soil organisms. The relation between the natural plant covering and the soil is perennially disturbed. The physical properties of the soil are injured by the repeated exposure and denudation; the soil fauna is unable to withstand such treatment and is permanently suppressed. More particularly, soils having iron concretions are converted into ferruginous plates firmly cemented together (Metzger), which can only support tall reed-grasses. Steppe fires ensure the permanence of this condition. The Forest Soil has been converted into a Steppe Soil.

These are the same conditions which formerly prevailed in our own latitudes and led to a deterioration of the soils. It was only with the evolution of a higher civilisation and a consequent continual increase in the value of land that it became worth Man's while to set to work to bring the soil into a more fertile condition such as is now shown by our cultivated fields.

The effects of the policy of land-robbery are repeated everywhere in the same way. No matter whether we consider formerly customary "brand-cultivation" (firing) of moors, or the destruction of forests in the plains of Northern Germany, Scandinavia or Great Britain, now covered by heaths, the process is always the same. The orginally Fertile Soils deteriorate, the soil loses its old properties and takes on a fresh character. Just as forest has been converted into heath in Germany, and Forest Soils into Heath Soils, so in Africa, for long ages, the dense primeval forest has continually been converted into Savannah, and Forest Soils into Steppe Soils.

In the Climatic Savannah, conditions are entirely different. Vageler has described a thorough investigation of the soils of the African Savannah. On the Mkatta Plateau the soil boundaries coincide with those of the plant formations. Here about 700 mm. (28 inches) of rain fall between December and March and convert the soil into a clay broth. There are many indications that the soil is intensely leached during the rainy season; during the dry season dissolved substances are added to the soil by the upward movement of the water. As far as can be seen from the description and the analyses these

are mainly compounds of iron. All the necessary conditions are fulfilled to render the iron mobile. The soil is closely permeated by the roots, the roots extend to considerable depths. In the saturated soil ferric compounds are reduced and converted into soluble salts. During the dry season the dissolved salts are carried up and deposited as ferric hydroxide. The extent to, and the form in which, aluminium can take part in this movement is not known. From experience in the Podsol districts and in the formation of pan it may be assumed that aluminium hydroxide is also carried. Vageler reports that in the Ugogo Steppe the soil types are very regularly distributed. The plateaus carry Steppe Bleached Earths; all slopes, on the other hand, are covered with Red Earths.

On the whole, the Savannah Soils have the character of Humid Soils; this is supported by the large extent to which iron and the small extent to which calcium is transported. According to this they are soils of tropical districts having a periodic climate which may be termed "semi-humid."

In recent years a start has been made in the investigation of the soils of the Dutch East Indies, and valuable results have already been published. The soils of Java and the other islands are to a large extent determined by the elevation. The climate is usually decidedly humid. Lang calls attention to the similarity between the soil-forming processes in these warm, moist districts and those of the moist portions of Europe.[90] Brown Earths and Bleached Earths are found as well as Red Earths. Laterite only occurs in the lower layers of the soil, and under the present climatic conditions is converted into Brown Earths by weathering. Many of the soils contain large quantites of humus. At elevations of from 2500 to 3000 metres (8000 to 10,000 feet) pure Humus Soils are found, to a certain extent as large deposits.

The literature is not poor in analyses of Tropical Soils, but unfortunately most of the publications are only procured with great difficulty. The analyses have mostly been carried out for practical purposes and often do not give sufficient information for Soil Science in general, especially as regards the stratification of the soil.

CHAPTER VI

SUMMARY OF THE CLASSIFICATION OF SOILS

ATTEMPTS to draw up a serviceable classification of soils which would satisfy the requirements of Agriculture as well as of Soil Science have been made on many different bases. In undertaking work of this kind the object in view should always be clearly expressed; to give the mind a summary of as large a number of facts as possible. A classification on a given basis is not correct or incorrect, not right or wrong, but is more or less suitable or unsuitable. A scientific classification or system can be regarded as the summary of a large number of definitions, and what holds for each individual case, holds for the whole. Every definition expresses in a short formula the state of the science at that time. It will, and must, change with the advance of our knowledge.

Unfortunately it is not superfluous to point out that definitions, and this is true of all definitions, are products of the human mind, created for the purpose of presenting a clearer view and easier correlation of the data with the theories prevailing at the time. Nowhere are academic and scientific views more sharply opposed than in definitions. The academic point of view has not yet been entirely overcome and still often prevails to a large extent even in the Natural Sciences.

A scientific classification must therefore be examined as to whether it summarises the available data, taking a broad view; if it fulfils this requirement, it is serviceable. It will be the more valuable, the more completely it displays all the properties of the things classified. This can only occur if the system corresponds to the evolution of the things, i.e. is built up on a genetic basis. This also gives the system a better chance of being permanent, since it is then capable of

expansion and so serving as a basis for the suitable arrangement of further information as the science advances.

The division of soil types into Dry or Arid Soils and Moist or Humid Soils was first carried out by Hilgard. Hilgard took climate as a basis and emphasised the sub-division into soils of arid climates and soils of humid climates. However, it is also justifiable to apply the terms to the soils themselves.[91]

Soils arise from the weathering of rocks. During weathering, substances are formed which are soluble in water. The water supplied by the rain is either evaporated or removed by drainage. If it is evaporated the dissolved salts remain in the soil. On the other hand drainage water removes the dissolved salts from the soil. The predominance of either process depends on the relation between the rainfall and the evaporation, and thus principally on climatic conditions. It is therefore justifiable to base the classification of soils on climate. All districts in which the rainfall exceeds the amount evaporated from the surface of the soil get rid of the surplus in the form of drainage water; these are soils of humid climates, or briefly Humid Soils. With these are contrasted the soils of districts in which the evaporation is high, so that considerably more water can be evaporated than is supplied to the soil by the rain. Under such conditions drainage water is not formed, or at all events, not in considerable quantities. These are soils of arid climates, or briefly Arid Soils.

Theoretically transitional soils should be found inserted between the two divisions, in which evaporation and the formation of drainage water balance one another. In practice such soils are not known. On the other hand, there are many types of soil in districts having a periodic climate, which during one part of the year are subjected to humid conditions, during another part of the year to arid conditions. According to the preponderance of the soil properties we can distinguish between Semi-Arid and Semi-Humid Soils. These types were formerly collectively called "semi-arid"; semi-humid soils have not previously been recognised; they have a considerably more limited distribution than soils having an arid character. The reason for this is probably to be found in the fact that

with equal quantities of water the effects produced by the ascending current are more marked than those due to the descending current (see page 16).

We thus arrive at the following classification of soils into main divisions:—

Division A. Humid Soils.

Sub-division I: Soils of uniformly moist climates.

Sub-division II: Soils of districts with a periodic climate (the humid character being predominant).

Division B. Arid Soils.

Sub-division I: Soils of districts with a periodic climate (the arid character being predominant).

Sub-division II: Soils of uniformly dry climates.

Humid Soils.

Humid Soils undergo leaching by seepage water. The amount of leaching is determined by the rate of weathering and by the solvent action of water. Both these, but particularly weathering, increase with a rise in temperature. Another factor in the formation of soils is the amount of organic matter in the soil. This is undoubtedly determined by the relation between the synthesis of organic substances and their decay, and here, again, temperature has a great influence. Hence we may base our further divisions of the Humid Soils on the prevailing mean temperature of the districts in which they occur, and so classify our soils according to the usual climatic zones.

We must then distinguish between soils of the following climates:—

1. *Frigid.*
2. *Temperate.* (*a*) Cool temperate. (*b*) Warm temperate.
3. *Sub-Tropical.*
4. *Tropical.*

Arid Soils are directly influenced by the intensity of the evaporation, indirectly by the relation between the rainfall

and the amount of the evaporation. The intensity of the prevailing evaporation is dependent on the temperature and on the moisture content of the air. The classification of the climates would be best based on a value which included both these factors. The saturation deficit fulfils these requirements. Unfortunately this value, equally important in Biology as well as in Soil Science, is not found in meteorological publications, and the relative humidity figures given are of little use even as a basis upon which to calculate the saturation deficit. For the present we can only speak of climates as being more or less decidedly dry, and make our sub-divisions on these lines. So far as soils are concerned three will be sufficient; we may distinguish between the soils of:—

1. Moderately dry climates.
2. Dry climates.
3. Very dry climates.

The soils of districts with a periodic climate are classified in the same way as the two principal groups.

Those agencies affecting the properties of the soil but which are not connected with climatic factors, have been termed "local influences," and the soils to which they give rise "Local Soils." Individual properties of the soil, such for instance as those due to the texture of the soil, can be found in every climate. The names of soils such as Sand, Clay, etc. are not bases for the classification of soils but rather aids for their description, for which, however, they are of great importance. Their use is always permissible if it is borne in mind that the designation only expresses a definite property of the soil, this being the texture or grain-size of the examples given.

Difficulties arise in the classification of Shifting Soils; dunes, for instance, are found in all climates on the sea coast, in moderately dry climates in the neighbourhood of rivers whose flood-level varies greatly, as well as in dry climates on all sandy areas. It will probably be advisable to treat them as Local Soils in connection with the respective dominant soil types; they therefore recur in different climatic groups.

It will be best to consider the influence of organisms on

the properties of the soil in connection with the description of the soil. The soil description will be simpler or more exhaustive according to the purpose for which it is intended.

An examination of the table (facing p. 118) shows that the arrangement of the soil types into soil zones and soil regions is apparently a suitable way of dividing up soils into large classes; the consideration of local factors leads to a further sub-division and enables us to group the various Local Soils within the broad limits of the climatic zones. In this way the great variation of soil receives due consideration without disturbing the intrinsic continuity of the series.

The table gives an idea of the present state of our knowledge of soils.

A CLASSIFICATION OF SOILS.

		Periodic		
	Humid.	**Semi-humid**	**Semi-arid**	**Arid**
I. Cold Zones and Regions.	1. ARCTIC : Tesselated Soils (Flowing Earths) 2. BOREAL : Tundra Soils. Local Soils : Peat hillock, tundra. 3. REGIONAL : Frost-shattered Soils. Mountain Meadow Soils. Mountain Peat Soils. On limestone : Alpine humus.		Soils of the interior of Greenland, Spitzbergen. Regional : Deserts and Tablelands of Asia.	
II. Cool-Temperate Zone.	A.—NORTHERN GREY EARTHS. (a) Northern Sand-humus Soils. (b) Podsol. (c) Forest Bleached Earths. LOCAL SOILS. 1. *Sub-aqueous Soils.* (a) Mineral Soils under water. (b) Muds or Sapropels. (c) Humus Soils. α Fen Soils. β Carr Soils. γ Moss Soils. δ Vegetable Mould Soils. 2. *Soils under the Influence of the Ground Water.* (a) Glei Soils. (b) Meadow Soils. (c) Limonite Soils. 3. *Soils receiving continual additions of material.* (a) Warp Soils. (b) Marsh Soils. 4. *Saline Soils of the Bleached Earths.* 5. *Flowing Earths.* Regional : Grey Earth of various types. B.—BROWN EARTHS. *Local Soils* (Numerous, according to the parent rock). (a) Massive Rocks. (b) Schists. (c) Sandstones. (d) Calcareous Rocks. (e) Karst Red Earths.	Reef Soils on limestone. In the north : Black Soils rich in humus. In the south : Red Earths.	Soil types greatly influenced by the increases in evaporation and reduction in rainfall. Temperature effects reduced. 1. STEPPE BLACK EARTHS. *Climate moderately dry.* Tschernosem. Prairie Soils. *Climate very dry.* Chestnut Brown Soils. Soils coloured brown by humus. 2. STEPPE BLEACHED EARTHS.	
III. Sub-Tropical.	Yellow Earths (?)		*Yellow Earths.* *Red Earths.* *Sub-tropical Black Earths.* (a) Regur. (b) Tîrs. (c) Southern prairie of North America. *Crusting Soils.*	Crusting Soils. Desert Soils.
IV. Tropical.	Laterite. Red Earths. Red Loams. Tropical Brown Earths. Tropical Bleached Earths.	Savannah Soils.	Red Earths.	Tropical Desert Soils.

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SUBJECT INDEX

Abschlämmassen, 33
Acid humus, 9, 15, 43, 76
Acid rocks, 26
Aeration, limits of, 17
Age of soils, geological, 36
Alkali soils, 102
Alluvial drift, 33
Alluvial soils, 83
Alpine humus, 64
Alumina, 11, 21
Animals, 38
Arid soils, 49, 53, 116
Aspect, 31
Atmosphere, soil, 4

Basalt, weathering of, 28
Beeches, 41, 42
Beech soils, 42, 44
Black alkali soils, 102, 103
Black cotton soils, 105
Black earths, 48
Black earths (Sub-Tropical), 105
Black water, 109
Bleached earths, 47, 100
Bleached forest soils, 72
Blowing dust and sand, 34
Bog formation, 67
Bog ore, 20
Boreal zone, 23
Broad leaved trees, 42
Brown earths, 48, 85
Brown earths (Glinka), 98
Buried soils, 36
Buttery clay, 60

Calcareous soils, 26, 88–92
Calcium carbonate, deposition of, 14, 18, 19, 23
Calcium carbonate horizon, 17
Calcium sulphate, 17
Capillary water, 12
Carbonates, influence on weathering, 66, 90
Carr, 76
Cereals, 44
Change of climate, 36
Chestnut brown soils, 48, 97
Classification of soils, 46
Clay, 10, 15, 30
Climate, 1
Climate, change of, 36
Climate, effect on soil formation, 1
Climate, periodic, 50
Climate, soil, 3, 40
Climatic factors, 2
Cold rigor, 10
Cold soils, 90
Cold zones and regions, 64
Colloids, 15
Colour of soils, 46
Communities, plant, 40
Coniferous forest, 42
Covering, soil, 3
Creep, 33
Creep soils, 33
Crusting soils, 106
Crystallisation, 17
Cultivated soils, 44

Deciduous forest, 40
Decomposition of rocks, 6
Decomposition of silicates, 9
Definitions, 47, 114
Definition of soil, 1
Deflocculation, 34
Degraded Tschernosem, 96
Derived soils, 28
Description of soils, 118
Desert lac, 107
Desert soils, 107
Destroyers of humus, 78
Detrital soils, 28, 64
Disintegration of rocks, 6
Drift, alluvial, 33
Drift, glacial, 28
Drowning of woodland, 67
Dry peat, 69
Dry soils, 49, 53, 117
Dung, 23
Dust, 29
Dust soils, 34

Earths. *See* Soils
Earthworms, 38
Efflata soils, 35
Eluvial horizon, 68
Eluvial soils, 28
Evaporation, 2, 3

Expansion,
Explosive frost, 3, 63
Exposure, 31

Fenland vegetation, 75
Fen peat, 75
Ferric hydroxide, 11, 19, 20, 74, 80
Fixity of soils, 32
Floating soils, 85
Flowing earths, 32, 34, 85
Fluvioglacial soils, 29
Forest, broad-leaved, 42
Forest, coniferous, 42
Forest peat, 76
Forest soils, 40
Forest soils, grey, 70
Formation of humus, 22
Formation, agencies of soil, 5
Formations, plant, 40, 42
Frigid zones, soils of, 62
Frost, 3, 63
Frost-shattered soils, 64
Fungi, 39

Garden soils, 44
Glacial soils, 28
Glei soils, 20, 73, 81
Grain-size, 29
Granite, weathering of, 27
Grasses, 42, 78
Grassland, 42
Gravel, 30
Gravitational water, 12
Grey earths, northern, 66
Grey forest soils, 70
Grey steppe soils, 99
Ground water, 13
Gypsum, 17

Hamri, 106
Hardpan, 104
Hillock tundra, 63
Horizons A-, B-, C-, 56
Horizons in the soil, 17
Humid soils, 49, 53, 116
Humidity of the air, 3
Humus, 22
Humus, acid or sour, 43, 76
Humus, colloidal, 15
Humus destroyers, 78
Humus soils, 74
Hydrargillite, 110
Hydrolysis, 9
Hygroscopic water, 12

Ice soils, 65
Illuvial horizon, 57

Inclination, 31
Intermediate moors, 77
Iron hydroxide, 11, 18, 19, 81
Iron pan, 69
Iron sulphide, 82, 85

Jointing of rocks, 53, 85

Karst red earths, 92
Karst soils, 89
Klei soils, 84
Knick, 84

Lac, desert, 107
"Land-robbery," 111
Laterite, 49, 109
Leaching of the soil, 55
Limestone, 31, 53, 89
Limits of aeration, 17
Limonite, 80
Limonite soils, 20, 80, 82
Loams, 30
Loams, red, 110
Local soils, 24, 117
Local soils of the N. bleached earths, 72
Loess, 27

Macroflora, 39
Marshes, 84
Mass action, 8
Meadow formations, 42
Meadow ore, 20
Meadow soils, 81
Micro-flora, 38
Mixed moors, 77
Mkatta plateau, 52, 112
Molkenböden, 60
Moor soils, 78
Moraine soils, 29
"Mosses," 77
Moss peat, 77
Mould, 22, 78
Mountain meadow soils, 64
Mountain peat soils, 64
Mountain top detritus, 63
Muck soils, 73
Mud soils, 73

Non-quartz, 26
Normal soil, 56
Nut structure, 71

Ochre, 20
Orchard bush, 110

Pan, 69
Pasture soils, 21, 42, 80
Peat, 22, 23
Peat, dry, 69
Peat hillock tundra, 63
Peat marl, 80
Peat soils, 74
Peat soils, mountain, 64
Peat soils, succession of, 78
Peat soils, transformation of, 78
Peat soils, weathering of, 79
Peat, sour or acid, 9, 15, 44, 76
Periodic climate, 50
Pig wallow land, 106
Pines, 41
Pine soils, 42
Plants, 38
Podsol soils, 60, 67, 68
Prairie soils, 97
Precipitation, 2
Primeval forest soils, 109
Primeval forest soils, conversion to steppe, 111
Profile, 32
Puddling, 34

Quartz, 26
Quicksands, 34
Quick soils, 85

Rainfall, 2
Red earths, 48
Red earths, Karst, 92
Red earths, Sub-Tropical, 105
Red earths, Tropical, 107
Red loams, 110
Reed swamp formation, 43
Reef red earths, 93
Reef soils, 3, 30
Regur, 105
Relic soil, 37
Rendzina, 91
Rock, Influence of parent, 25, 66
Rock tundra, 63

Saline soils, 85, 102
Salts soluble in the soil, 16
Sand, 19
Sand, erosion by, 6
Sapropel, 73
Savannah, 110
Savannah formation, 42
Schlick, 84
Screes, 28
Semiarid, 52
Semiarid soils, 50, 93
Semihumid, 52
Semihumid soils, 50, 111, 115
Shifting soils, 32
Silicates, weathering of, 9
Silicic acid, 21, 26
Single grain structure, 34
Sinking soils, 85
Situation, 30
Slime soils, 74
Slope, 30
Soda in the soil, 100
Soil classification, 114
Soil climate, 3, 39
Soil covering, 3
Soil definition, 1
Soil description, 118
Soil formation, agencies of, 5
Soil profile, 32
Soil regions, 59
Soil solution, 15
Soil stratification, 55
Soil texture, 30
Soil wash, 56
Soil zones, climatic, 54, 59, 62
Soils—
Alkali, 102
Alluvial, 33
Arid, 49, 53, 116
Beech, 42, 44
Black, 48
Black Alkali, 101, 104
Black Cotton, 105
Black (Sub-Tropical), 106
Bleached, 47, 100
Bleached forest, 72
Brown, 48, 85
Brown (Glinka), 98
Calcareous, 26, 88–92
Carr, 76
Chestnut brown, 48, 97
Creep, 33
Crusting, 106
Degraded Tschernosem, 96
Desert, 107
Dry, 49, 53, 117
Dust, 34
Efflata, 35
Eluvial, 28
Floating, 85
Flowing, 32, 34, 85
Fluvioglacial, 29
Forest, 40
Forest, Grey, 70
Frost-shattered, 64
Garden, 44
Glacial, 28
Glei, 20, 73, 81
Grey Forest, 70

Grey, Northern, 66
Grey Steppe, 99
Humid, 49, 53, 116
Humus, 74
Ice, 65
Karst, 89
Karst Red, 92
Klei, 84
Knick, 84
Laterite, 49, 109
Limonite, 20, 80, 82
Loams, 30
Loams, Red, 110
Local, 24, 117
Local, of the N. Bleached Earths, 72
Loess, 27
Meadow, 81
Moor, 78
Mountain Meadow, 64
Mountain Peat, 64
Muck, 73
Mud, 73
Pasture, 21, 42, 80
Peat, 74
Peat Hillock Tundra, 63
Pine, 42
Podsol, 60, 67, 68
Prairie, 97
Primeval Forest, 109
Quick, 85
Red, 48
Red, Karst, 92
Red, Sub-Tropical, 105
Red, Tropical, 107
Red Loams, 110
Reef, 3, 30
Reef Red, 93
Relic, 37
Rendzina, 91
Saline, 85, 102
Sapropel, 73
Savannah, 110
Schlick, 84
Semiarid, 50, 93
Semihumid, 50, 111, 115
Shifting, 32
Sinking, 85
Slime, 74
Solonetz, 103
Solutschak, 103
Steppe, 71, 93
Steppe Black, 94
Steppe Bleached, 99
Sub-Tropical Black, 105
Sub-Tropical Red, 105
Szek, 103
Tesselated, 62
Tirs, 106
Tropical Bleached, 109
Tropical Red, 110
Tundra, 63
Tschernosem, 48, 51, 94
Tschernosem, Degraded, 96
Warp, 35, 83
White Alkali, 102
Woodland, Grey, 70
Yellow, 48, 104
Solonetz, 103
Sols, Humus, 15
Solutschak, 103
Sour humus, 43, 76
Steppe black earths, 94
Steppe bleached earths, 99
Steppe formation, 42
Steppe soils, 71, 93
Stones, 30
Stratifigraphy, 55
Substratum, 57
Sub-Tropical black earths, 105
Sub-Tropical red earths, 105
Succession of peat soils, 78
Swimming mountains, 34
Szek soils, 103

Talus, 29
Temperate zones, 65
Temperature, 2
Tesselated soils, 62
Texture, 29
Tirs, 106
Topsoil, 56
Transitional moors, 77
Tropical bleached earths, 109
Tropical red earths, 110
Tundra, 63
Tschernosem, 48, 51, 94
Tschernosem, degraded, 96
Tschernosem, composition of, 96

Vegetable moulds soils, 78
Volcanic ashes, 35

Warp soils, 35, 83
Wash, 56
Water, capillary, 12
Water, chemical action of, 9
Water current, ascending, 16
Water current, descending, 14
Water, gravitational, 12
Water, hygroscopic, 12
Waterlogging of soil, 67
Water-table, 13
Weathering, 5

Weathering, chemical, 6
Weathering, horizon of, 56
Weathering, physical, 6
Weathering of peat, 79
Weathering of silicates, 9
White alkali soils, 102
Woodland, 40
Woodland soils, grey, 70
Wood peat, 76

Yellow soils, 48, 104

Zones and regions, 59
Zones, boundaries, 54
Zones, climatic soil, 54, 59, 62
Zones, cold, 64
Zones, Sub-Tropical, 105
Zones, temperate, soils of, 65
Zones, tropical, 109

INDEX TO AUTHORS

Atterberg, 29

Blanckenhorn, 107
Bogoslowsky, 64
Buchanan, 49, 109

Clements, 24

Dokutschajew, 54, 60, 70

Ebermayr, 65

Falckenstein, V. von, 60
Fallou, 27, 87, 88
Fischer, H., 74
Frosterus, 73

Glinka, 33, 48, 68, 87, 95, 98, 99, 101
Grebe, 88

Hilgard, 49, 53, 115
Höfle, 31

Kostytschew, 51
Krauss, 4

Lang, 10, 113

Metzger, 112
Mohr, 35
Müller, 70

Nordenskjöld, 62

Potonié,
Prassolow, 65

Richthofen, 105

Ssuskatschew, 63

Treitz, 35

Vageler, 52, 113

Weber, 74
Whitley, 60
Wollny, 3
Wysotski, 81

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